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STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

Geology and Mineral Resources of the Neenach Quadrangle, California

BULLETIN 153
1950

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SAN FRANCISCO BULLETIN 153 MARCH 1950

GEOLOGY AND MINERAL RESOURCES of the NEENACH QUADRANGLE, CALIFORNIA

By JOHN H. WIESE
U. S. Department of the Interior, Geological Survey

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LETTER OF TRANSMITTAL

To His Excellency
THE HONORABLE EARL WARREN
Governor of the State of California

SIR: I have the honor to transmit herewith Bulletin 153, *Geology and Mineral Resources of the Neenach Quadrangle, California,* prepared under the direction of Olaf P. Jenkins, Chief of the Division of Mines, Department of Natural Resources. The report is accompanied by a number of maps, charts, and illustrations, including a detailed geologic map, lithographed in color, of the 15-minute Neenach quadrangle. The area of this quadrangle is nearly 250 square miles, covering portions of the Tehachapi Mountains and Antelope Valley in Kern and Los Angeles Counties. Two famous earthquake fault zones, the San Andreas and Garlock faults, pass through the area mapped. Their junction point lies several miles to the west at Gorman and Lebec where State Highway 99 cuts through the Tejon Pass. It is significant that the area mapped contains tin deposits discovered and prospected during World War I. These, together with gold, copper, tungsten, molybdenum, marble and limestone, crushed rock, volcanic ash and ground water, are described in this bulletin.

The author, John H. Wiese, prepared the report while in the employ of the United States Geological Survey and in connection with graduate study at the University of California at Los Angeles. Cooperating with the Federal Survey and the State University, the State Division has helped to sponsor the undertaking and is publishing the results of the work as one of its series of bulletins.

Respectfully submitted,

WARREN T. HANNUM, Director
Department of Natural Resources

December 7, 1949

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GEOLOGY AND MINERAL RESOURCES OF THE NEENACH QUADRANGLE, CALIFORNIA*

By John H. Wiese **

ABSTRACT

The Neenach quadrangle includes an area of 247 square miles whose center is about 60 miles northwest of Los Angeles. It spans the western end of Antelope Valley, and extends north across the Tehachapi Mountains and south into the foothills of Liebre Mountain.

The oldest rocks exposed are gneiss and schist of pre-Cambrian (?) age. These, and a contact-metamorphosed limestone, limy shale, and sandstone series of Paleozoic (?) age, are intruded by Jurassic (?) plutonic rocks of five main types: gabbro, diorite, granite, quartz diorite, and quartz monzonite. In general the sequence of intrusion is from basic to acidic.

At the southern edge of the quadrangle, volcanic rocks composed chiefly of andesite flows and tuffs of Miocene (?) age overlie the older crystalline rocks unconformably, and grade upward into coarse terrestrial sediments. Fossiliferous marine sandstone and conglomerate of the upper Miocene Santa Margarita formation rest on granite at the western edge of the quadrangle. These marine deposits may have been laid down contemporaneously with some of the terrestrial sediments, but where the two formations occur together they are in fault contact, and their relative age cannot be determined.

Lacustrine deposits, probably of Pliocene age, are the youngest Tertiary rocks. Continental sandstone and silt south of the San Andreas fault are referred tentatively to the Pleistocene. A large part of the quadrangle is covered by terrace gravel and older and younger alluvium.

Faults are the dominant structural features throughout the area, but there are a few folds in the Tertiary rocks, chiefly adjacent to the San Andreas fault zone. Two major faults that trend N. 70° E. through the Tehachapi Mountains are part of the Garlock fault system. The direction and amount of movement of these two faults could not be determined, but some features suggest lateral displacements of several miles, the south block in each case having moved relatively eastward. They bound a block of schist ½ mile to 1½ miles wide which extends completely across the quadrangle. Gneiss, gabbro, and diorite lie north of the schist, on the north slope of the range, and granite, quartz diorite, and metasediments occur on the south slope.

In the southwest corner of the quadrangle a segment of the San Andreas fault zone 4 miles long separates Tertiary rocks on the north from quartz monzonite on the south. The block south of the San Andreas fault apparently moved relatively upward several thousand feet since Tertiary time, and may have moved relatively northwestward as well.

In the wedge between the Garlock and San Andreas fault zones at least 10 smaller faults trend northeast. Two of these display evidence of small vertical movements in recent times, though on one, the Piñon Hill

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** Geologist, U. S. Geological Survey.

fault, the greater movement has been horizontal since Tertiary time, the south block apparently having moved relatively northeastward 2 to 3 miles.

The only mineral production came from one tin mine and a group of three small gold mines, though there are many small workings on the south flank of the Tehachapi Range which explore gossan, tactite, or quartz bodies containing minor amounts of gold, tin, tungsten, copper, or iron. There are no indications of petroleum; two holes drilled in Antelope Valley about 1920 were dry. Exploitation of the deep ground-water supply began with the drilling of six wells in 1946.

INTRODUCTION

The Neenach quadrangle covers the western portions of the Tehachapi Mountains and Antelope Valley, partly in Kern County and partly in Los Angeles County, California. Its position, indicated on the accompanying map (fig. 1), is between 34° 45′ and 35° 00′ north latitude and between 118° 30′ and 118° 45′ west longitude. It covers a total area of

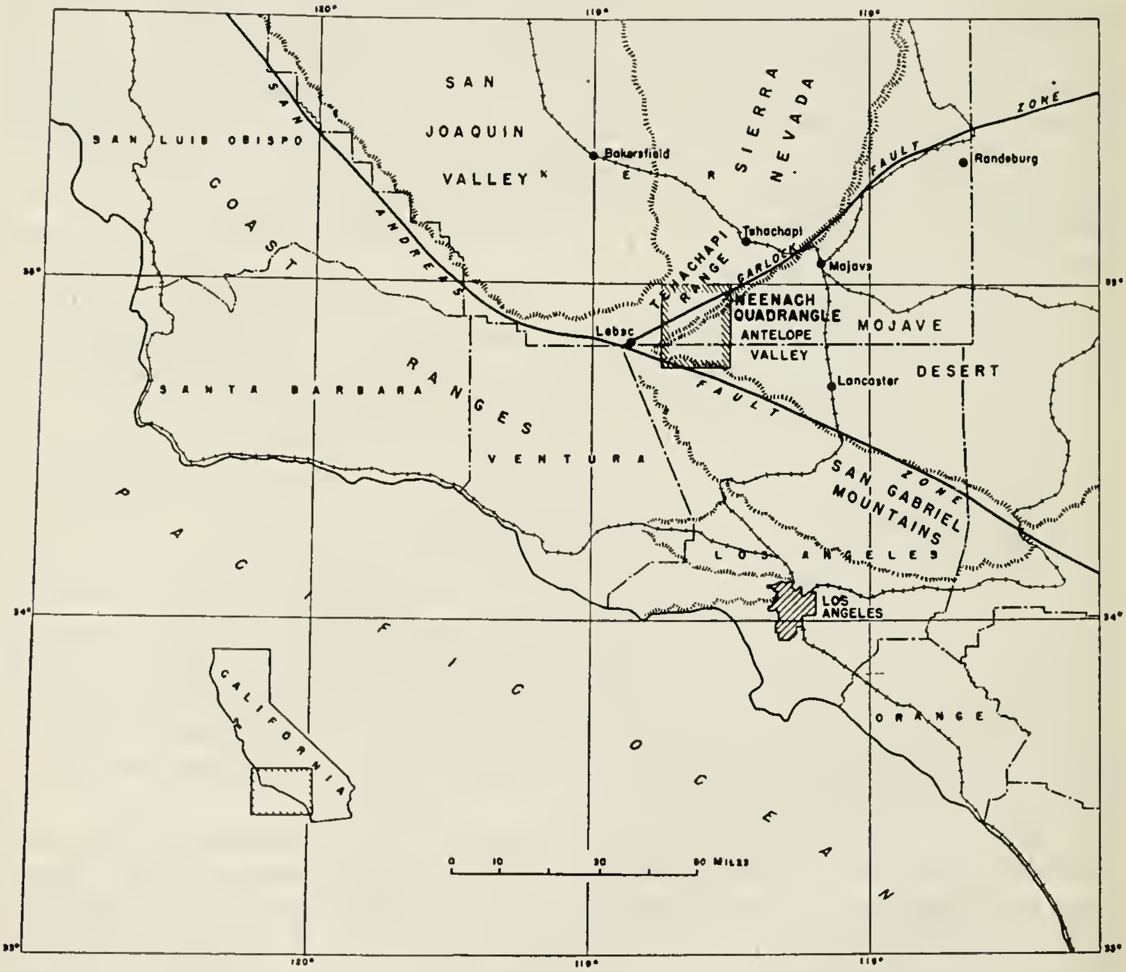

FIGURE 1. Index map of southern California showing location of the Neenach quadrangle.

247 square miles: 130 square miles of the Tehachapi Mountains, 40 square miles of the northern foothills of Liebre Mountain and the low hills around Quail Lake, and 77 square miles in Antelope Valley.

In 1900 the U. S. Geological Survey mapped the topography of this area as the northeast quarter of the Tejon quadrangle, on a scale of 1 : 125,000. The topographic map of the Neenach quadrangle used as the base for the present geologic mapping was made by the U. S. Army in 1943 on a scale of 1 : 62,500.

There are no towns in the Neenach quadrangle. Although about 30 places of habitation are scattered along the margins of Antelope Valley, many of them are vacant except during the harvest season.

Purpose of the Report, Field Work, and Acknowledgments

Late in 1942 a deposit of high-grade tin ore was discovered near the western edge of the Tehachapi Mountains, about 4½ miles north of Quail Lake. Other smaller deposits were found during 1943. In the spring of 1944 the writer was assigned to map these deposits in detail as part of a joint exploratory program carried out by the U. S. Geological Survey and U. S. Bureau of Mines. The results of this work, which continued during the summer of that year, were published in January 1946.[1]

In July 1946 the writer was instructed to map the Neenach quadrangle, which contained most of the known tin deposits, with the purpose of relating these deposits to the intrusive sequence and finding the structural controls responsible for their localization. Field work began July 1, 1946 and continued until the end of November. During October and November the writer was efficiently assisted by Spencer F. Fine, who did much of the detailed mapping of the Tertiary rocks.

It is a pleasure to acknowledge the aid of Brodie Hamilton, president of the Tejon Ranch Company, and to thank many of the ranch employees, particularly A. G. Beall, W. R. Hall, Frank Appodaca, and Harry Prittie, who furnished much information about the district. Thanks are also due Willard Mallery, discoverer of the tin deposits, for his enthusiastic cooperation throughout the course of the work.

The writer is indebted to many of his colleagues on the Geological Survey for their assistance. Especial thanks are due Cordell Durrell, James Gilluly, and Ward Smith for their suggestions and help at all stages of the work, and to H. G. Ferguson for his valuable criticisms of this report in manuscript form.

Location and Accessibility

The northwest corner of the Neenach quadrangle lies at the southern edge of San Joaquin Valley, about 30 miles southeast of the city of Bakersfield. The quadrangle completely spans the Tehachapi Mountains and crosses the western end of Antelope Valley, a triangular valley which opens east toward the Mojave Desert. At Quail Lake the western boundary is exactly on the drainage divide between the interior drainage of the Mojave Desert and the headwaters of Piru Creek, which flow south into the Santa Clara River and then to the Pacific Ocean near Oxnard.

State Highway 138, the main paved road on the quadrangle, runs along the southern edge of Antelope Valley. Four miles west of the quadrangle it connects with U. S. Highway 99, the trunk highway between Los Angeles and the cities in San Joaquin Valley. About 20 miles east of the quadrangle it connects with U. S. Highway 6 and the main line of the Southern Pacific Railroad at Lancaster.

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[1] Wiese, J. H., and Page, L. R., Tin deposits of the Gorman district, Kern County, California : California Div. Mines Rept. 42, pp. 31-52, 1946.

The other maintained roads in the quadrangle are unpaved except for short oiled sections. One follows the line of the Los Angeles Aqueduct, another the line of the General Petroleum Company pipeline down the center of the valley, and another crosses the Tehachapi Mountains along the route of a power transmission line at the east edge of quadrangle.

Several dirt roads lead north from Highway 138 to canyons on the south slope of the Tehachapi Range. A graded dirt road branches from Highway 99 at Lebec, 7 miles west of the mapped area, and continues northeast until it enters the Neenach quadrangle near the head of Bear Trap Canyon. These dirt roads are generally passable except for a few weeks during the worst winter storms.

Topography

The Tehachapi Mountains are roughly wedge-shaped, being 25 miles wide at their northern limit, where they merge with the Sierra Nevada at Tehachapi Pass, and 9 miles wide at their southwest end, where they join the Coast Ranges at Tejon Pass. The Neenach quadrangle covers the southern fourth of the range. Most of the crest within the mapped area is above 5,500 feet in altitude, and in two places it rises to 6,800 feet. The range is markedly asymmetrical. The north slope is gentler and reaches an altitude of 1,500 feet at the edge of San Joaquin Valley; the south slope reaches an altitude of 3,500 to 4,000 feet at the edge of Antelope Valley.

The crest of the range in the area mapped is nearly straight, trending about N. 60° E. North of the crest the spurs trend northwest, following in broad outline the strike of the underlying metamorphic rocks. On the south slope the topography is less regular, being controlled by the distribution of resistant limestone bodies. A broad, deeply dissected, raised alluvial fan flanks the southern edge of the mountains, widening from a mile at the mouth of Little Sycamore Canyon to 6 miles just east of Little Oak Canyon.

The west end of Antelope Valley is closed by low rounded hills underlain by soft Tertiary sediments. A mantle of fan gravel, locally a hundred feet thick, covers much of this area.

At the south edge of the quadrangle are the foothills of Liebre Mountain, a northwest-trending granitic mass which rises from 3,000 feet at the valley's edge to 5,800 feet about 3 miles south of the quadrangle. A narrow alluvium-floored valley, eroded along the course of the San Andreas fault zone, separates the foothills from the main mountain mass.

Climate

The climate of most of the region is arid. The precipitation ranges from 17 inches in the higher western parts to 7 inches at the east end of Antelope Valley; nearly all precipitation falls between the months of November and March. In the summer the daytime temperatures frequently exceed 100°; there are a few cool days. In the winter the range is greater, from only a few degrees above zero to about 70°. During much of the year a strong wind sweeps over the Tehachapi Mountains from the north, and is concentrated particularly at the two low spots in the range, the head of Cottonwood Canyon and north of Cottonwood Creek.

Vegetation

Joshua trees, sage, and creosote bush cover the uncultivated portions of the valley floor and the alluvial fans on both sides. The lower hills support a sporadic cover, locally quite dense, of scrub oak, juniper, digger pine, chamise, manzanita, and buckthorn, with sycamore, cottonwood, live oak, and willow in the creek bottoms. Above 5,000 feet, particularly on protected north slopes, grow tall groves of fir, yellow pine, and a few cedars.

Land Use

The hills and part of the valley floor are grazing land for cattle and a few sheep. About 30 square miles of the valley is planted with wheat and barley. Most of the almond groves planted along the highway during the boom of the early 1900's now are neglected. In 1946 several deep water wells were drilled to furnish water for the irrigation of several hundred acres of potatoes. The deep water supply will undoubtedly be further exploited in the next few years.

Water Supply

Streams on the north slope of the Tehachapi Mountains are mostly permanent, though their volume diminishes considerably in late autumn. On the south slope only those of Cottonwood Canyon, Bronco Canyon, and Cottonwood Creek live through an average summer, although there are enough scattered small springs to provide water for domestic and stock use. All the creek beds at the south edge of Antelope Valley are dry in the summer months except the one fed by the spring at La Liebre Ranch. Quail Lake, fed mainly by winter and spring run-off, has no outlet and is brackish.

Surface run-off from the mountains reaches the center of Antelope Valley only rarely, during prolonged winter rains, summer flash floods, or after winters of heavy snowfall.

Previous Work

Johnson [2] outlined some of the broader structural features of part of the Neenach area during his study of the artesian water supply of lower Antelope Valley. Simpson's [3] map of the adjoining Elizabeth Lake quadrangle shows the eastward continuation of the Garlock and San Andreas fault systems. Hoots' [4] map of the south edge of San Joaquin Valley deals only with the Tertiary sediments there, which extend into the Tehachapi Range within a quarter of a mile of the northwest corner of the present quadrangle.

A list of reports dealing more or less directly with the geology of the Neenach quadrangle is included at the end of this paper.

DESCRIPTIVE GEOLOGY

The rocks exposed in the Neenach quadrangle range in age from pre-Cambrian (?) to Recent. Metamorphosed sediments of pre-Cambrian (?) and Paleozoic (?) age, intruded by a plutonic igneous sequence of Jurassic (?) age, make up most of the Tehachapi Mountains. Tertiary continental and marine sediments and lavas are exposed in the low hills bordering Antelope Valley. The valley itself is floored with Recent alluvium.

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[2] Johnson, H. R., Water resources of Antelope Valley, California: U. S. Geol. Survey Water-Supply Paper 278, 1911.

[3] Simpson, E. C., Geology and mineral resources of the Elizabeth Lake quadrangle, California: California Div. Mines Rept. 30, pp. 371-415, 1934.

[4] Hoots, H. W., Geology and oil resources along the southern border of San Joaquin Valley, California: U. S. Geol. Survey Bull. 812, pp. 243-332, 1929.

Pre-Cambrian (?) Rocks

Pelona Schist

Distribution and General Features

A sequence of greenstone schist and quartzite assigned to the Pelona schist is exposed as a narrow but continuous strip, ranging in width from ½ mile to 1½ miles, which extends the whole width of the quadrangle and continues on either side for at least several miles. Steeply dipping faults of the Garlock fault zone separate the schist from diorite on the north and from granite and quartz diorite on the south.

The schist appears to represent a metamorphosed sequence of fine sandstone and basic tuffaceous shale, although some basic lavas and minor intrusives may be included. The maximum exposed thickness of nearly 5,000 feet, consists mainly of green amphibole or chlorite schist, with subordinate thinly bedded pinkish quartzite, and brown mica schist. Neither the top nor the base of the sequence is seen. Faint cross bedding in the quartzite layers suggests that the base is toward the south.

Throughout the sequence the schistosity seems to be nearly parallel with the bedding as defined by the thin quartzite layers, and in most of the area the beds strike parallel to the enclosing faults and dip vertically or steeply northward. Divergences from this attitude are mostly in landslide or slumped areas. The schist erodes to form smooth rounded grassy slopes and broad ridges scarred with sharp narrow gullies and landslides. Locally the quartzite layers are expressed as steep northeast-trending strike ridges or as low welts on the rounded slopes. Springs and small ponds are numerous, especially in landslide areas.

Petrography

The Pelona schist of this area can be separated into several fairly distinct rock types, though gradations between these types are sharp, and two or three may be represented in one hand specimen. The dominant rock type is mica-chlorite-albite schist, in which there are wide variations in the proportion of mica to chlorite and in the degree of schistosity. A less dominant rock type is amphibole-albite schist, a dark-green rock containing abundant albite porphyroblasts. Fine-grained, light-colored quartzite and quartz-biotite schist make up about a fourth of the formation. There are a few outcrops of actinolite schist and small masses of coarse actinolite. A few cobbles of talc schist were found at float. Lenses of white quartz, some as large as 10 feet across and 100 feet long, occur in all parts of the section, generally with their long dimension parallel to the strike of the schist.

Mica-Chlorite-Albite Schist. The mica-chlorite-albite schist is a fine-grained, greenish-gray rock in which individual grains can just be distinguished with a hand lens. In most places the schistosity is only moderately developed, although near faults it is quite prominent. As determined from thin section the rock is 55 percent albite, 25 percent quartz, and 20 percent mica and chlorite in variable proportions. The albite occurs as untwinned, more or less equant, partly rounded, sievelike porphyroblasts containing swarms of tiny inclusions of quartz, apatite, and unidentified dusty particles. These inclusions are crowded toward the centers of the crystals; the outer rims are nearly free of them. Wrapping sinuously around the albite, and locally contained in it, are trains of bent, contorted, and broken scales of chlorite and pale-greenish, weakly pleochroic mica.

Epidote and clinozoisite are both present in minor amount as small ragged grains. In addition to the quartz grains included in the porphyroblasts, there are larger grains in the chloritic bands. All the quartz shows undulatory extinction. In several places clear white albite veinlets 1 millimeter or 2 millimeters wide crosscut the schistosity.

Amphibole-Albite Schist. The most striking rock type of the Pelona schist is emerald-green amphibole schist containing abundant rounded clear white albite porphyroblasts ranging in size from 0.5 millimeter to 4 millimeters. The silky sheen of the planes of schistosity results from the subparallel arrangement of tiny fibrous crystals of amphibole wrapped around the porphyroblasts.

In thin section short discontinuous lamellar twinning and undulatory extinction may be seen in the albite grains. They are quite clear except for streams of minute dark particles which course through the whole rock, parallel to the foliation, without regard for crystal boundaries. The amphibole needles are strongly pleochroic with $X =$ pale green, $Y =$ green, and $Z =$ blue green; they have a (—) 2V near 70°, positive elongation, and birefringence around 0.020 with β about 1.695. The angle $Z \wedge c$ is about 15°. These data correspond most closely to the properties of an actinolite high in ferrotremolite. Stubby prisms of apatite are fairly common, pyrrhotite is less so. Some of the albite porphyroblasts contain narrow veinlets of clinozoisite.

Quartz-Biotite Schist and Quartzite. Quartz-biotite schist and quartzite generally occur together and there are all gradations from one to the other. The schist is made up of lenticular layers of granular white quartz varying from paper thinness to several centimeters, separated by films of dark golden-brown biotite. With increasing thickness of the quartz layers the rock becomes a massive quartzite, though individual beds, indicated by lines of dark impurities, remain less than 2 centimeters thick. In some places biotite is subordinate or absent and fine muscovite is present. Porphyroblasts of albite, filled with many quartz inclusions like those in the chlorite-mica schist, occur in all but the purest quartzite and seem to favor the mica-rich layers. Tiny dodecahedrons of faintly pink or colorless garnet occur with the feldspar in a few layers. The biotite is strongly pleochroic and either wraps around grains of quartz or feldspar or forms isolated flakes within these minerals.

Actinolite Schist and Talc. There are several outcrops of nearly pure actinolite schist near the south edge of the schist block, on the east wall of Cottonwood Creek. The rock is an apple-green aggregate of curved radiating needles of actinolite 5 to 20 millimeters long. Silvery scales of talc lie along the cleavages, adding to the luster of the rock. Locally there are masses of impure talc a few inches across. Talc float also was found near the north edge of the schist block at the head of Tunis Creek. No large bodies were seen within the quadrangle, such as the masses of talc 25 feet across noted by Simpson [5] in the Pelona schist of the Elizabeth Lake quadrangle. Simpson believed the talc was formed by the alteration of ultrabasic dike rock.

Age of the Schist

As the block of Pelona schist is bounded by faults, evidence of the age of this rock is lacking within the quadrangle except that it is older than the granite pegmatite dikes intruding it near the western boundary of the area; and also older than the unmetamorphosed lamprophyre dikes in it near the eastern boundary.

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[5] Simpson, E. C., Geology and mineral resources of the Elizabeth Lake quadrangle, California: California Div. Mines Rept. 30, p. 380, 1934.

The Pelona schist was named and first described by Hershey [6] from the exposures on Pelona Ridge, 22 miles south of the Neenach quadrangle. Hershey considered the schist pre-Cambrian and the equivalent of the schist exposed at Randsburg, 55 miles northeast of the Neenach area, called the Rand schist. Hulin [7] found fragments of what he believed were his Rand schist in probable lower Paleozoic sediments in the Randsburg area, and therefore concluded the Rand schist was pre-Cambrian.

Simpson [8] was unable to determine the age of the Pelona schist in the Elizabeth Lake quadrangle, which includes Pelona Ridge, more closely than pre-Eocene, but considered it pre-Cambrian, largely on its resemblance to the Rand schist. Hill [9] studied all the known areas of Pelona schist in the San Gabriel Mountains, and concluded that it was probably pre-Cambrian and equivalent to the Rand schist, though he acknowledged it might be as young as Jurassic.

The rocks lying between the two branches of the Garlock fault in the Neenach quadrangle are identical in all respects to the Pelona schist at the type locality on Pelona Ridge, and there is little doubt they once formed part of the same mass. Simpson mapped the northeast continuations of these two faults as the Oak Creek Canyon fault, and called the schist lying between them part of the Bean Canyon series, of probable Triassic age, though the schist is identical with the Pelona that he mapped south of Antelope Valley.

Structure and Metamorphism

In the Elizabeth Lake quadrangle, at the west end of Sierra Pelona, the Pelona schist has been deformed into a broad anticline several miles wide. In the Neenach quadrangle the schist dips steeply or is vertical. In the Randsburg quadrangle Hulin's Rand schist is only gently warped and few dips exceed 15°. In all three quadrangles the schistosity is broadly parallel to the quartzite layers which probably show the attitude of the bedding and seems to be as marked in areas of high dip as in horizontal beds, as well developed near intrusive contacts as it is away from them.

This evidence suggests that the schistosity is not necessarily the result of strong tilting or folding and probably was impressed on the rock before the intrusion of igneous bodies now exposed; therefore, in the Neenach quadrangle, movement of the schist block into its present position in the Garlock fault zone probably did not cause the schistosity, though it may have accentuated it in certain shear zones.

Conditions of Deposition

Only fine-grained detrital material is recognizable in the Pelona schist, indicating accumulation of the original sediment in quiet water. The wide extent of the formation and its even bedding suggest marine conditions and a moderate distance from shore.

The albite porphyroblasts are so uniformly distributed, and show so little relation to intrusive rocks or to crosscutting structures, that they must have been formed from recrystallization of material originally deposited in the sediment. This richness in soda, the relatively large amount of magnesia represented in actinolite and the complementary poverty in alumina and silica could have been contributed by basic igneous material. Most of the schist is thinly interlayered with beds of quartzite, suggesting that the igneous material was in the form of tuff.

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[6] Hershey, O. H., The Quaternary of Southern California: Univ. California Dept. Geol. Bull., vol. 3, pp. 1-29, 1902.

[7] Hulin, C. D., Geology and ore deposits of the Randsburg quadrangle, California: California Min. Bur. Bull. 95, p. 33, 1925.

[8] Op. cit.

[9] Hill, H. S., Petrography of the Pelona schist of southern California, Unpub. M. A. thesis, Pomona College, 1939.

Gneiss Complex

Occurrence and General Features

The oldest rock unit north of the Garlock fault zone is a complex consisting largely of biotite gneiss with minor amounts of mica schist, quartzite, and marble. The gneiss is bounded by younger gabbro and diorite intrusions. Foliation in the gneiss is strongest adjacent to the gabbro and follows a gentle S-shape, wrapping around the gabbro at the northwest corner of the area then curving south and east, and finally turning northeast again across upper El Paso Creek. At the western edge a northeast-trending fault offsets the contact between gabbro and gneiss a distance of about 1 mile.

About a third of the gneiss complex is readily identifiable as metamorphosed sedimentary rock, consisting of mica schist interlayered with marble and quartzite; a third seems to be igneous, a nearly massive quartz-biotite-feldspar rock; the remainder is an injection gneiss consisting of an intimate mixture of these varieties, grading into each other.

Injection gneiss makes up a large part of the hills along lower El Paso Creek; it extends north beyond the quadrangle boundary and passes beneath Tertiary sediments along the flank of the mountains. The injection gneiss weathers readily and forms a subdued, grass-covered topography. Even in outcrop the rock is so friable it can easily be crushed in the hand. The few outcrops are generally mantled with dark-green moss. Included lenses of marble or quartzite crop out as low, light-colored welts which rise a few feet above the general surface.

Banding in the gneiss is due to an alternation of dark- and light-colored layers ranging from a fraction of a millimeter to several centimeters in thickness (pls. 7*A*, 9). The parallel flakes of fine-grained black biotite which make up most of the dark layers are accompanied by a little plagioclase and quartz. The light bands are generally thicker and more lenticular, and locally cut across the general trend of the banding for short distances. They are composed of pegmatitic plagioclase and quartz with only a small percentage of black biotite. Although, on a large scale, the banding is smooth and regular, in detail there are many tight folds and crinkles that range from about an inch to a foot in height.

The injection gneiss grades southeastward into coarser-grained biotite gneiss which generally contains a little hornblende. This rock is more resistant to weathering and makes up the higher forested ridges near the head of El Paso Creek. It, too, is composed mainly of plagioclase, quartz, and biotite, but the proportion of biotite to quartz is much lower and there is little or no segregation into bands. The texture is typically igneous. The plagioclase is unzoned and has a fairly uniform composition, about $An_{48\text{-}50}$ (calcic andesine). The biotite is dark brown, usually occurring as well-formed thin plates, and may or may not be accompanied by a little dark-green hornblende. Zircon, sphene, and apatite are generally present in small amount. A few slides contained fine-grained chlorite.

Lenses of metamorphosed rock that are clearly of sedimentary origin are included in both the injection gneiss and biotite gneiss. The main ridge west of El Paso Creek, near the north boundary of the quadrangle, is capped by a lens of white dolomitic marble 600 feet long and as much as 100 feet wide. Smaller marble bodies crop out to the north, close to the gabbro contact. Parts of the smaller masses are metamorphosed to hard, greenish, fine-grained rock composed of alternating thin bands, some of diopside and labradorite, others of quartz. Rounded zircon grains are abundant. Thin beds of granulite, formed from the recrystallization of impure quartzite, are interlayered in the injection gneiss in the extreme northwest corner of the quadrangle. This rock is a banded mosaic of coarse quartz and sodic plagioclase, the latter in part replaced by zoisite. Sphene and rounded zircon crystals are abundant.

Origin of the Rock

The gneiss complex probably represents a highly metamorphosed series of fine-grained sedimentary rocks—shale, dolomitic limestone, and sandstone—to which has been added silica-rich igneous material. The purer layers of sandstone and limestone, being more massive as well as more stable chemically under the conditions which metamorphosed the surrounding rock, retained their identity, whereas the shale was greatly changed, first to biotite schist and then to gneiss, as crystallization continued and pegmatitic material was added along the planes of schistosity.

Age of the Gneiss

The only age relationship directly determinable is that the gneiss is older than the gabbro, diorite, and pegmatite which intrude it. The meager evidence available suggests that the gneiss is probably pre-Cambrian in age, and that it may represent metamorphosed and injected equivalents of the Pelona schist, though it may well be older or younger than the schist.

At the edge of Cottonwood Creek, about halfway between Schamp Ranch and White Oak Lodge, the diorite contains large inclusions of biotite schist and hornblende-rich rock quite similar to parts of the Pelona schist. This is nearly 5 miles from the nearest outcrop of biotite gneiss, but it may suggest that the gneiss, too, was derived from the Pelona schist. Graphitic marble lenses similar to those included in the gneiss are known in the Pelona schist at its type locality. The metamorphism is considered pre-Jurassic, as unmetamorphosed pegmatite dikes intruding the gneiss complex are thought to be related to the Jurassic (?) intrusives. These dikes have a northeast strike and cross the gneiss without regard to its structure, and show none of the crushing effects common to parts of the older rocks.

Paleozoic (?) Rocks (undifferentiated)

Occurrence and Character

The isolated patches of metamorphosed strata which lie on the south slope of the Tehachapi Mountains represent remnants of the former country rock into which the granitic magma rose. They include contact-metamorphosed limestone, limy shale, and sandstone, all of undetermined, but possibly Paleozoic, age. The largest bodies lie on the granite west of the Piñon Hill fault. The moderately to steeply dipping beds are sharply truncated by the granite contact, which is nearly a plane sloping gently southeast. East of the fault the bodies are smaller and have steep contacts with the igneous rock.

Bluish-gray or white limestone and marble, the dominant rocks, make up about three-fourths of the sequence of Paleozoic (?) rocks. The remainder is gray or white quartzite, green and pink lime-silicate hornfels, and somewhat schistose black biotite hornfels. The marble is generally graphitic and may owe its bluish color to this. Near intrusive contacts, however, it is altered to a massive, sugary, white or pale-yellowish marble with no traces of bedding and no graphite. At a distance from the contact the grain size ranges from very fine to 2 centimeters from layer to layer, but it is usually uniform along a single bed. Thin intercalated calc-hornfels layers of pink zoisite or green epidote are present in many of the limestone beds, and are best developed within a few hundred feet of the granite. These silicated beds are strongly jointed and poorly exposed. The quartzite is well-bedded, generally in layers a few feet thick, but the rock is highly jointed and there are few outcrops. Indistinct cross bedding is visible in some beds west of Quinn Ranch.

Fine-grained brecciated dolomite makes up most of the thrust plates west of Cottonwood Canyon. The rock is light gray when fresh and weathers white. It gives off H_2S when freshly broken. Innumerable thin white calcite veinlets have healed the fractures in the rock.

Thickness and Distribution

Though the general resemblance of lithology, structure, and degree and type of metamorphism suggest that they are all approximately the same unit, the lack of any recognizable stratigraphic markers, either key beds or fossils, makes it impossible to correlate the isolated outcrops. North of Quinn Ranch the section consists of 4,000 feet of bluish-white coarse marble at the base, 2,500 feet of gray and reddish sandy limestone, pinkish-gray quartzite, and black biotite hornfels near the center, and 2,500 feet of medium- to coarsely crystalline bluish-gray marble at the top. Marble and minor amounts of calc-silicate hornfels make up a section of about 3,000 feet on the mesalike hill between Cottonwood and Little Sycamore Canyons. The differences in lithology suggest that these rocks are not equivalent to any part of the section above Quinn Ranch; hence the total thickness may be more than 12,000 feet. The large amount of faulting west of Cottonwood Canyon precludes measurement of a stratigraphic section there.

A train of nearly 50 small inclusions of metamorphic rock was mapped along the toe of the range between Canyon de la Lecheria and the mouth of Little Oak Canyon. These inclusions, mostly lens-shaped, range in length from 100 to 2,000 feet. Their long axes, parallel to the bedding, strike east or northeast. Their sides dip steeply in most cases. They are mostly white marble, converted along their edges to dark garnet-epidote-quartz tactite, locally containing scheelite.

Wedges of white and bluish schistose marble, from a foot to a few hundred feet wide, lie between Pelona schist and granitic rocks along the south branch of the Garlock fault for nearly half the width of the quadrangle. The marble is largely graphitic and in places coarsely crystalline, but shows no characteristic features which might correlate it with any of the other limestone bodies which lie outside the fault zone.

The vertically dipping limestone and hornfels body enclosed in quartz diorite 2½ miles south of Twin Lakes bears little resemblance to the rocks of any of the inclusions to the west. The hornfels contain sillimanite, not recognized in the other rocks, and the limestone is more thinly bedded and sandier than in other places. It resembles the metamorphosed limestone a few miles east that Simpson [10] mapped as part of the Bean Canyon series of possible Triassic age. In the present mapping, however, this body is included with the undifferentiated Paleozoic (?) rocks.

The quartz monzonite near the southeast corner of the quadrangle contains 11 limestone [11] inclusions large enough to show on the map, and several smaller ones. They consist largely of white or gray limestone with minor amounts of pink or green calc-silicate hornfels, quartzite, and gray quartz-biotite hornfels. The beds dip steeply and in general trend northwest. They resemble the metamorphosed strata in the Tehachapi Mountains and are similar in degree and type of metamorphism, but a more positive correlation cannot be made.

Age and Correlation

The metamorphosed sedimentary series is assigned tentatively to the Paleozoic because it is lithologically similar to Paleozoic rocks in the Inyo Range and the Randsburg district, and is intruded by plutonic rocks thought to be of Jurassic age. Though this correlation and assignment of age is weak, it is the best that can be offered at the present time.

No fossils have been found in this series, either within the Neenach quadrangle or in adjacent areas along the south flank of the Tehachapi Mountains. Goodyear [12] believed he found crinoid fragments in a similar marble in Brite Valley, about 13 miles to the north. Some rounded calcite crystals in a matrix of fine-grained bluish calcite occur at several places in the Neenach quadrangle, mainly in the less-metamorphosed limestone west of Cottonwood Canyon, and these may represent altered crinoid fragments or possibly fusilinids, but even their identification as fossils is problematical. Recrystallization of the limestone in all places has proceeded so far as to obliterate most of the original features of the rock, and even if fossils were present when the rock was deposited, it is not likely that they remain.

No metavolcanic rocks were recognized in the Paleozoic (?) sedimentary sequence of the Neenach quadrangle; therefore the sequence is probably not the same as the metamorphic series in the Elizabeth Lake quadrangle, which consists largely of metavolcanics with interbedded marble, slate, and quartzite, which Simpson considered Triassic, or in part Jurassic, in age because lithologically they resemble known Triassic rocks of the Inyo Range.

The upper age limit is fixed by correlating the intruding granitic rocks with those of the Sierra Nevada batholith, which is late Jurassic or early Cretaceous in age.

Jurassic (?) Intrusive Rocks

Five plutonic intrusive rocks, ranging in composition from gabbro to granite, were mapped in the Neenach quadrangle. Gabbro and diorite are north of the Garlock fault zone; granite and quartz diorite crop out along the south flank of the Tehachapi Mountains; quartz monzonite underlies the Tertiary rocks at the south edge of Antelope Valley.

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[10] Simpson, E. C., Geology and mineral resources of the Elizabeth Lake quadrangle, California: California Div. Mines Rept. 30, pp. 371-415, 1934.

[11] The term "limestone" used here and frequently hereafter in this report refers to the recrystallized and metamorphosed limestone or marble characteristic of the Paleozoic (?) rocks, undifferentiated.

[12] Goodyear, W. A., Kern County: California Div. Mines Rept. 8, pp. 309-324, 1888.

Because of the large-scale faulting, the record of the intrusive history is fragmentary. The gabbro is probably the oldest, closely followed by the diorite. All the more acid rocks are probably younger, but the relative ages of the granite, quartz diorite and quartz monzonite are undetermined.

Assignment of the intrusive rocks to a Jurassic (?) age is by inference only, for they penetrate no fossiliferous strata, nor are fragments of them incorporated in sediments older than Miocene. They closely resemble rock types composing the Sierra Nevada batholith whose age is known to be late Jurassic or early Cretaceous, and the age assignment is based on this resemblance. The gabbro and diorite have certain structural differences from the more silicic rocks exposed in the quadrangle, and it may be argued that they should be correlated with similar intrusives in the San Gabriel Mountains, thought to be pre-Cambrian in age. Conclusive data are lacking, however, and for convenience all the intrusive rocks of the Neenach quadrangle are here considered of Jurassic (?) age.

Gabbro

Occurrence and Character

In an area of about 6 square miles in the northwest corner of the quadrangle is an intrusive mass of hornblende gabbro, roughly teardrop-shaped in plan, which has steeply dipping flowage banding parallel to its walls. Banding in the enclosing gneiss parallels that in the gabbro and the contact between the two rocks is everywhere concordant and gradational, though the gabbro clearly intrudes the gneiss. An intermediate zone several hundred feet wide grades from biotite gneiss penetrated by a few dikes of gabbro, through lenticular injection gneiss of interfingering gneiss and gabbro to massive gabbro enclosing a few indistinct remnants of gneiss with blurred boundaries. This border zone is nowhere well exposed, it weathers readily and is generally marked by a line of draws and saddles.

The typical gabbro is a hard fine-grained dark-gray rock composed almost entirely of plagioclase feldspar and hornblende, with the former slightly more abundant. Individual crystals are usually less than 3 millimeters in length although local coarser-grained gabbro near the center of the intrusive contains hornblende prisms as long as 15 millimeters. The rock is quite fresh, the hornblende is black and shiny in hand specimen and the plagioclase is white and vitreous, except on some surfaces where both minerals are stained yellow by iron oxide. The weathered surfaces of a few outcrops are cellular black shells composed almost wholly of hornblende, the interstitial feldspar having been entirely weathered out.

The average gabbro is composed of about 55 percent labradorite, 42 percent hornblende, and 3 percent of magnetite, ilmenite, and apatite. There is little alteration except for the rare occurrence of chlorite, which forms at the edges of hornblende. The plagioclase forms elongate subhedral laths, some showing zoning from An_{72} to An_{50}, though most crystals are less strongly zoned. Those in the central, coarser parts of the gabbro seem to be most calcic, averaging around An_{67}. Those in the finer peripheral parts average An_{52}.

The hornblende is strongly pleochroic from yellow to olive green to greenish blue, and forms well-shaped prisms, commonly finely twinned.

Magnetite and ilmenite are generally in hornblende. Apatite occurs as short clear prisms randomly oriented. There are a few small prisms of zircon.

Garnet-Bearing Gabbro. A few small rounded grains of red almandine garnet may be seen in many outcrops of the gabbro, particularly in the finer-grained border facies, but in some places several hundreds of feet within the gabbro body, well-formed garnet dodecahedrons from 1 centimeter to 8 centimeters in diameter make up several percent of the rock, giving it a striking mottled appearance. Each garnet encloses numerous labradorite and magnetite grains and commonly is surrounded by an aureole a centimeter or less in thickness of lighter-colored rock consisting almost wholly of labradorite. Murdoch [13] believed the garnets were metacrysts which formed in place within a relatively short time interval either before or after the consolidation of the gabbro, the material for their formation coming from solution of hornblende in the vicinity. Newly formed labradorite then took the place of the dissolved hornblende. Schurmann [14] studied a suite of specimens from this locality and concluded that as he found the melting points of labradorite and almandine to be nearly the same and higher than that of the hornblende, the former two minerals crystallized first and simultaneously. The formation of garnet required excess iron, resulting in an iron-impoverished zone around each garnet where little or no hornblende could crystallize.

A chemical analysis of the gabbro, as given by Schurmann [14] is as follows:

Analysis of gabbro from Neenach quadrangle, California
Chemical composition
(Drs. von Tongeren, analysts)

	Percent		Percent
SiO_2	46.16	K_2O	0.18
Al_2O_3	24.15	H_2O +	0.51
Fe_2O_3	4.36	H_2O —	0.04
FeO	6.11	CO_2	0.04
MnO	0.09	TiO_2	1.60
MgO	4.53	P_2O_5	0.29
CaO	9.43		
Na_2O	2.26		99.75

This analysis is remarkable for the high-alumina and low-potash content. The specimen probably contained more plagioclase than the typical gabbro.

Relation to Other Rocks

The gabbro clearly intrudes the gneiss and is therefore younger. The intermediate injection zone, the concordance of foliation of the two rocks and the lack of cataclastic textures indicates that the intrusion took place at fairly great depth, where high heat and pressure made possible deformation by flowage.

On the other hand the gabbro is older than the large mass of hornblende diorite which encloses both the gabbro and gneiss. This age relation is well shown in outcrops along upper Tunis Creek, where the diorite sends dikes and offshoots into the gabbro, generally parallel to its foliation. There is an intermediate zone of mixed gabbro and diorite like that at the contact between gabbro and gneiss, and consequently the boundary shown on the map is generalized. The genetic relationship of the gabbro and diorite is discussed below.

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[13] Murdoch, Joseph, Some garnet crystals from California: Jour. Geology, vol. 47, p. 197, 1939.

[14] Schurmann, H. M. E., Granatführender diorit aus der Sierra Nevada, Kalifornien: Neues Jahrb., Beilage-Band 74, Abt. A., pp. 244, 250, 1938.

Form and Internal Structure

The gabbro body is teardrop-shaped in plan, with the walls of the rounded part dipping toward the center. The narrow end is enclosed concordantly between gneiss and diorite. A fault offsets the border at the eastern side. Foliation in the enclosing gneiss is best developed in the zone of injection gneiss and metasediments which lies next to the gabbro and becomes less distinct outward, grading into more massive gneiss. The gabbro, then, is a funnel-shaped body occurring in the most highly foliate part of the gneiss.

The diorite lying against the south edge of the gabbro is younger and we may assume that the gabbro when emplaced was completely surrounded by gneiss. The concordant contacts, form, and concentric flow banding of the gabbro give the impression that it was emplaced from below, expanding upward, or from the southeast and expanded toward the north. The horizon chosen for the entrance of the gabbro logically would be the most easily penetrated part of the gneiss, in this case a series consisting of micaceous injection gneiss and thinly bedded metasediments.

The fault which breaks the margin of the gabbro may well have been formed at the time of intrusion, as the walls gave way to continued expansion of the gabbro. If the map were viewed as a cross section, the gabbro body would appear quite similar in form to a faulted laccolith.

Diorite

Occurrence and Character

Hornblende diorite crops out over an area of some 25 square miles on the north flank of the Tehachapi Mountains, north of the Garlock fault zone. Beyond the quadrangle boundaries it extends for at least several miles to the west, and Simpson [15] has mapped it for nearly 3 miles to the east, across part of the Elizabeth Lake quadrangle. Although locally it varies in composition, grain size, and structure, on a broad scale the diorite is homogeneous, and undoubtedly is all part of a single intrusive mass. In composition it ranges from hornblende diorite, containing neither quartz nor biotite, to quartz-biotite diorite with little hornblende. In general, however, quartz and biotite together are less than 10 percent of the rock. A mild crushing, probably protoclastic, is shown by nearly all the diorite. In addition, cataclastic effects are prominent along the Garlock fault and in most of the diorite in the eastern part of the quadrangle, from Schamp Ranch to Twin Lakes, where there are several zones of mylonite.

The dominant variety of diorite is a moderately coarse-grained gray rock which consists of about equal amounts of dark- and light-colored minerals and has a fairly prominent foliation. In thin section it is composed of 50 percent andesine, 47 percent hornblende, and 3 percent magnetite, apatite, sphene, zircon, and garnet, in descending order of abundance. The plagioclase crystals in it are subhedral, tabular parallel to 010, and have both pericline and albite twinning. In the normal rock, zoning of the plagioclase is insignificant, the composition being about medium andesine, ranging from An_{38} to An_{45}. Along the branch of the Garlock fault which limits the south edge of the diorite mass, however, the diorite has been so metamorphosed that each andesine grain has a narrow rim of nearly pure albite.

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[15] Simpson, E. C., Geology and mineral resources of the Elizabeth Lake quadrangle, California: California Div. Mines Rept. 30, pp. 371-415, 1934.

The hornblende is dark green in hand specimen, pleochroic from dark brownish to greenish in thin section. Commonly it occurs as well-formed prisms enclosing magnetite. In much of the diorite, the common hornblende is fringed by a rim of pale bluish-green hornblende, probably of deuteric origin. Apatite occurs as fairly large hexagonal prisms as well as tiny ones enclosed in feldspar.

The texture of the rock is interlocking and typically igneous. Its foliation is an original feature, parallel orientation of crystals and crystal aggregates having resulted from flowage. There are very few monomineralic bands, and these are ptygmatically folded, short pegmatitic layers 1 centimeter to 5 centimeters thick composed of hornblende or feldspar of slightly larger grain size than the typical rock. Other bands, of fine-grained plagioclase and hornblende together, are most common near the contact with gabbro and may be reworked inclusions of the latter.

Quartz-Biotite Diorite. There is every gradation from quartz-free hornblende diorite to quartz-biotite diorite with little hornblende. Quartz and biotite always occur together, and seem to have replaced the earlier-formed minerals, though locally some quartz may be interstitial.

The quartz, in most cases, replaces feldspar though it may replace hornblende as well. Seen in thin section, it forms tiny blebs or irregular salients into the plagioclase, guided locally by cleavage or crystal boundaries. Under low magnification the quartzose patches may be seen to cross the slide as nearly continuous pinching and swelling bands. Biotite also seems to occur as discontinuous trains, generally best developed in plagioclase in the vicinity of magnetite. Its replacement origin is less obvious as the crystals are better formed and do not make up bands as continuous as those of quartz grains.

The evidence cited indicates that this replacement was a late magmatic or deuteric process, going on after protoclastic crushing of the rock and probably guided largely by fractures which formed then. Later cataclastic deformation is evidenced by bent biotite flakes and strained quartz grains, as well as by the occurrence of zones of mylonite in the replaced rock in the eastern part of the area.

Alteration Along the Garlock Fault

Strong shearing of the diorite is evident in many places along the fault which forms its southern boundary and generally extends several hundred feet away from the fault. In hand specimens the rock shows a stronger foliation than the typical diorite and is much less coherent. Augen of plagioclase and hornblende are common. The boundaries of the crystals are indistinct and the whole rock has a dull, altered appearance. In places it is heavily iron-stained. In thin section the plagioclase is seen to be strongly bent and fractured and secondary twinning is developed. Crystals of hornblende and biotite are also broken and bent and the quartz is shattered, showing strong strain shadows under crossed nicols.

In addition to the crushing there are important mineralogic changes. A rim of nearly pure albite surrounds each andesine grain. Considerable chlorite, with lesser calcite and epidote, has developed at the expense of hornblende. Muscovite is generally present, either as finely divided sericite along fractures in plagioclase or as larger plates between grains of other minerals. The large amount of iron oxide suggests the former presence of sulfides, particularly near the west edge of the quadrangle, but none were seen in the rock. Silicification is common, varying in degree from tiny veinlets of quartz to massive lenses of pure white quartz measurable in tens of feet, enclosing isolated remnants of diorite. These lenses are alined parallel to the fault and to the foliation in the diorite.

A road cut high on the west bank of Cottonwood Creek exposes a large body of garnet-bearing amphibolite faulted against the Pelona schist. Westward along this branch of the Garlock fault, smaller garnet-hornblende bodies lie against the fault just north of Sandberg's Lodge, on the upper reaches of El Paso Creek. Each of these basic masses grades into hornblende-plagioclase rock away from the fault. It is not clear whether they represent inclusions, possibly metamorphosed impure limestone or volcanic material, whose position against the fault is fortuitous, or whether they are ultra-metamorphosed portions of the hornblende diorite, which were formed by movement along the fault at considerable depth and are now exposed, due to later movement, uplift, and erosion.

Mylonite

The mountain north of White Oak Lodge is traversed by several east-west shear zones along which bands of mylonite from a few inches to 10 feet wide have developed (pl. 5). Poor exposures make them difficult to trace laterally, but they probably are at least several hundreds of feet long. Their western limit within the quadrangle is just north of Schamp Ranch. The mylonites strike parallel to the foliation in the enclosing diorite for the most part, and grade outward into it. The dominant rock type produced is a hard, green, fine-grained, flinty rock with fairly prominent but delicate banding. Rounded, flattened phenocrysts of hornblende and plagioclase as large as 2 millimeters long lie in certain of the bands, but the grains in the remainder of the rock cannot be made out with a hand lens. Under the microscope the fine-grained minerals of the groundmass have a pronounced flow structure, streaming around the larger grains. The mineral composition is the same as in the quartz diorite, with the addition of a little epidote.

There is some segregation into lighter and darker laminae, but the volume of each is so small it could have been formed from a single crystal of the normal igneous rock. In some places partial recrystallization has made a dark foliated rock with flattened augen of plagioclase enclosed in a matrix of undistorted, nearly parallel tiny flakes of red-brown biotite, fine-grained quartz plagioclase, and pale hornblende.

A silicified shear zone in the diorite extends from the saddle about 2 miles west of Schamp Ranch a distance of 2 miles in a northwest direction. The zone is a few hundred feet across and has gradational boundaries with the unaltered diorite on either side. The rock of the shear zone differs from the rock described above in being mostly light-colored augen gneiss, with augen of pinkish microcline as large as 2 centimeters across enclosed in a matrix of fine-grained quartz, plagioclase, and biotite. Broken and contorted dikes of microcline-bearing pegmatite penetrate the augen gneiss, roughly parallel to its foliation.

Relation to Other Rocks

The diorite intrudes both the biotite gneiss and gabbro and is thus the youngest of the three. However, there is probably no great age difference between the diorite and gabbro. This is indicated by their similarities in structure, position in space, chemical and mineralogical composition, and the intimate mixing of the two rocks at their contact.

The gabbro, probably an early differentiate of a quartz diorite magma, represents the first stage of intrusion. After its solidification, a second impulse brought in the quartz diorite magma. Its protoclastic structure may indicate that it was crushed in place or that it was brought from another level, partially crystallized. In either case, silica-bearing solutions circulated through the crushed material, cementing and in part replacing the grains of plagioclase and hornblende. Probably some of the potash needed to form biotite was added as well, though some may have been contributed by the plagioclase as it was replaced.

Granite

General Features

Light-colored, medium- to coarse-grained biotite granite crops out, over an area of 25 square miles, on the southern part of the Tehachapi Mountains in the western part of the quadrangle, and eastward as a narrow band along the southern toe of the range almost to the eastern boundary. An additional 5 square miles within the range lies beneath a thin capping of limestone.

Granite may also underlie a large part of Antelope Valley, for at the south edge of the quadrangle there are a few small bodies of gneissoid granite with the quartz monzonite. These outcrops strongly resemble some facies of the granite at the north edge of the valley and may be part of the same intrusion.

The main mass of granite is relatively uniform in composition and texture and has no discernible foliation. It is strongly jointed but the joints show no consistent orientation. Within 100 to 200 feet of the overlying rocks there are conspicuous differences in texture, with variations from porphyry to aplite and pegmatite, although the mineralogic composition remains the same.

The granite breaks down into its constituent grains so readily that outcrops of unweathered granite are scarce even in the bottoms of deep canyons. Generally it forms rounded hills covered with grass and scattered oak, and with a few clusters of rounded residual boulders (pl. 6*A*).

In hand specimen the fresh granite is light gray or pinkish, with a medium-coarse grain and granitic texture. It is highly felsic and grades locally into alaskite. The dominant minerals are quartz, potash feldspar and plagioclase. Potash feldspar equals or slightly exceeds the total of the other two, and forms slightly larger, squarish crystals as much as 1 centimeter across, locally outlined by shreds of biotite. Biotite is the only dark constituent; it averages about 4 percent and rarely constitutes as much as 10 percent of the rock.

Microscopic examination shows the potash feldspar to be mainly microcline, generally carlsbad twins strongly intergrown with microperthitic albite. Locally myrmekite has developed at the edges of the microcline, apparently contemporaneously with the formation of the many wisps of biotite which also rim the microcline. The plagioclase crystals are smaller, and are zoned from An_{20} to An_{10} (medium to sodic oligoclase). All are twinned on the albite law and some on the carlsbad and pericline laws. They have a tendency to group in clusters of about half a dozen grains. The oligoclase ordinarily is idiomorphic against quartz and minor late orthoclase, but it also occurs as small rounded grains, not in optic continuity, in microcline. Thin plates of muscovite lie along the 010 and 001 cleavages of much of the oligoclase.

Quartz constitutes from 25 to 40 percent, and generally averages about 30 percent of the rock. It is clear, anhedral, and in coarse grains and crystal aggregates. All grains show undulatory extinction, some adjacent segments having axial divergence as large as 10°.

The biotite is dark green in thin section and strongly pleochroic. It occurs as small plates included in feldspar as well as the shreds surrounding the large microcline crystals. The larger flakes contain zircon grains surrounded by pleochroic halos. A little of the biotite has altered to chlorite.

Besides the universal strain shadows in the quartz, other cataclastic effects are the small-scale bending of mica, the bending and fracturing of plagioclase and local development of mortar structure at the rims of some of the larger crystals. On the whole, however, the effects of directed stress, though widespread, are not very intensive.

The gneissoid granite in the extreme southeast corner of the quadrangle, at the edge of Antelope Valley, forms outcrops too small to be differentiated on the map. The rock is light tan, composed almost entirely of light-colored minerals. Microcline, containing intergrowths of perthite and myrmekite, is the dominant mineral, forming about 55 percent of the rock. Elongate aggregates of strained quartz grains make up 35 percent and plagioclase the remaining 10 percent. Biotite occurs in clusters of fine shreds, locally altered at their edges to muscovite, and forms less than 3 percent of the rock. The plagioclase is strongly zoned, from An_{20} at the centers to $An_{0\text{-}5}$ at the rims. The soda-rich rims are clear, the rest of the crystals are dusty with fine-grained alteration products, including sericite.

The strong gneissoid foliation and the difference in composition of the plagioclase make it unlikely that the granite is closely related to the adjacent quartz monzonite and its metamorphism indicates that the granite is probably the older. As the contact is not exposed and dikes of one rock are not found in the other, it is impossible to determine their age relationship directly. No similar granite was found south of the San Andreas fault zone.

Marginal Facies of the Granite

In the marginal parts of the main granite intrusive, 10 to 200 feet from the overlying metamorphic rocks, the granite is usually somewhat finer grained, though the texture is granitic. Locally the rock is porphyritic, consisting of phenocrysts of feldspar and quartz as large as a centimeter across in a microgranitic matrix of quartz, feldspar, and biotite. The feldspar, generally microcline and less commonly oligoclase, is similar to the squarish carlsbad twins of the normal facies. The quartz grains commonly are partly rounded bipyramids. In thin section, the quartz pyramids are found to be polycrystalline mosaics of grains of slightly different optic orientation, probably the result of crushing. The fractures do not extend beyond the quartz grains.

The marginal 10 feet of granite and also the few apophyses penetrating the country rock are aplitic. The aplite is mainly a fine-grained intergrowth of microcline-microperthite, myrmekite, sodic plagioclase, and quartz, which locally grades into a coarser graphic texture. The rock is almost devoid of biotite, but contains sporadic flakes of muscovite. Owing to its fine grain size and lack of femic constituents, the aplite is relatively resistant to weathering and its float masks the surface far down the slope from its outcrop.

Shape of the Intrusive Body

West of the Piñon Hill fault the granite was formerly covered with limestone, and enough of this former cover remains to show the shape of the granite roof. The roof is nearly a plane, sloping quite evenly southeast at an angle of 6° to 7°. The projection of this plane between Pescado Creek and Cottonwood Canyon just clears the highest points of the intervening ridges and passes a few hundred feet or less above the crest of the range. The lateral walls are less definitely known, though the north edge of the intrusive may correspond closely to the contact with quartz diorite.

In the triangular area of limestone and hornfels west of Cottonwood Canyon three small granite outcrops represent cupolas that extend a hundred feet or so above the surrounding granite. These probably were fairly large departures from the even surface of the main contact, and detailed mapping of their contacts indicates that they were localized by pregranite faults. Near them the effect of mineralizers is notably stronger.

Remarkably few dikes interrupt the evenness of this roof. Fewer than a dozen dikes are seen along more than 25 miles of granite contact, and all these are small; most of them extend less than 10 feet beyond the main contact. In general they penetrate thinly bedded, schistose mica hornfels, though this rock type comprises less than a fourth of the invaded rock.

The intrusion apparently was passive, for though the beds of the metamorphosed cover dip steeply, they are truncated sharply at the contact, and even minor folding or crumpling is very rare. At the plane of the roof all the beds are cut off evenly, without regard to the nature of the rock or thickness of the bedding. The even surface at the base of the limestone may be the plane of a pregranite thrust fault, with the intrusion of the granite confined largely to the footwall block. This hypothesis is discussed further under the heading, *Structural Features.*

Age of the Granite

From the evidence contained within the area studied, the age of the intrusive can be stated only within wide limits. It is older than the Miocene (?) volcanics and younger than the Paleozoic (?) metamorphic rocks. In the adjacent Elizabeth Lake quadrangle, Simpson [16] considered the granitic intrusive rocks to be Jurassic, earlier than the Martinez formation (Paleocene) and later than his Bean Canyon series, which he concluded to be "probably in part Triassic and possibly in part Jurassic."

Although a definite statement of age is not possible, it is quite likely that the granite and other silicic intrusive rocks of the Neenach quadrangle are of the same age as the intrusives making up the Sierra Nevada batholith, that is, late Jurassic or early Cretaceous. It may be suggestive that the granite in the Neenach quadrangle is indistinguishable in hand specimen and thin section from the light-colored granite described by Knopf[17] as one of the common rock types of the Sierra Nevada, which crops out over large areas of the eastern slope at least as far south as Owens Lake.

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[16] Simpson, E. C., Geology and mineral resources of the Elizabeth Lake quadrangle, California: California Div. Mines Rept. 30, pp. 371-415, 1934.

Quartz Diorite

General Features and Occurrence

Light-colored quartz diorite underlies most of the south slope of the Tehachapi Mountains east of Canyon de la Lecheria, and from the head of Bear Trap Canyon to Liebre Twins it forms the straight, sharp crest of the range. The north boundary of the rock is the south branch of the Garlock fault. To the south and west it is in intrusive contact with granite except for 2 miles along the Piñon Hill fault. East of Little Oak Canyon terrace gravels cover the granite and overlap the quartz diorite. A few highly metamorphosed inclusions of limestone and hornfels occur in the quartz diorite on the lower slopes, near the granite contact. A large inclusion or roof pendant of limestone is part of the down-faulted block on the pediment at the eastern boundary of the quadrangle.

There are two main varieties of quartz diorite and several minor varieties. Where it lies against granite, the quartz is medium- or fine-grained and moderately foliate. It contains equal amounts of quartz and plagioclase (sodic andesine) and about 10 percent of dark-brown biotite. Sphene is a common accessory and is easily noted in hand specimens as honey-colored wedges 1 millimeter to 10 millimeters wide. The high degree of idiomorphism of the plagioclase and biotite is conspicuous. The white, opaque grains of andesine are nearly equant, each with several crystal faces developed. Their cloudiness, due to abundance of sericite, makes the grains contrast sharply with the clear, grayish, glassy quartz. Biotite also has a strong tendency toward equant habit, and occurs as subparallel thick tablets from 1 millimeter to 10 millimeters in size. The rock is weakly coherent, and, though they are comparatively fresh chemically, most specimens can be crushed in the hand. Exposures of coherent rock are very few (pl. 6-*B*). The area underlain by this type of quartz diorite is readily noted on aerial photographs, for it is covered with steep sand slopes and talus cones composed of fine-grained, white or yellowish granitic detritus on which only deep-rooted types of vegetation can survive.

In most places there is a fairly definite boundary between the facies of the quartz diorite just described and the second main type, which is coarser and more massive. In a few places the contact is knife-sharp and dikes of the coarser rock penetrate the other; elsewhere the contact is gradational over a few hundred feet. The coarser quartz diorite is a medium- to coarse-grained white rock composed of 35 percent quartz, 50 percent unzoned andesine (An_{33}) and 15 percent black biotite. Sphene is common but less abundant that in the border facies. The texture is hypidiomorphic granular. Biotite forms tiny shreds, larger flakes, or clusters having a faint tendency toward parallel orientation. Dark, fine-grained irregular inclusions of biotite-plagioclase rock are common in most outcrops. The majority are only an inch or two across and are alined with their long axes parallel to the foliation of the enclosing rock. Generally the coarser type of quartz diorite strongly resists weathering and erosion, and it makes up the backbone of the range and many of the outlying knobs, but those parts of the mass richer in dark inclusions form saddles.

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[17] Knopf, Adolph, A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 110, 1918.

On the pediment south of Cottonwood Creek typical coarse quartz diorite makes up only a fourth of the mass and forms the matrix surrounding a host of football-shaped blocks, from a few inches to several feet in diameter, of finer-grained, quartz-poor rock of dioritic composition. Only a short distance away is the larger limestone and hornfels body, and this hybrid dioritic rock may represent hornfels in the final stages of assimilation, though recrystallization has progressed too far to permit definite conclusions.

At many places along the north boundary of the quartz diorite the texture is cataclastic and along certain zones a few inches wide the rock has been altered to a harder, greenish, calcite-sericite-chlorite rock. The biotite grains are streaked out, the plagioclase bent, and the quartz shattered. These effects are quite likely related to movements along the Garlock fault.

Contact with Granite

The contact between granite and quartz diorite is nowhere well-exposed, and it is not known which rock unit is the older. From Bear Trap Canyon to the Piñon Hill fault the contact follows debris-filled canyons. At the saddle where it crosses the divide, dikes of pegmatite and aplite abound in the quartz diorite but none penetrate the granite. These dikes are rich in albite and are identical with those that seem to have originated in the massive quartz diorite, penetrating the marginal facies of the quartz diorite in other localities a few miles east. They do not resemble the microcline-rich pegmatite, related to the granite, which are found throughout the granite but which do not cross over into the quartz diorite.

Slickensides are common on pieces of granite float in the vicinity of the divide between Canyon de la Lecheria and Bear Trap Canyon, which suggests that there has been some folding or faulting there. It is possible that the local upwarp of the contact between granite and limestone may be the result of drag on a fault passing through the saddle, or the result of folding only. This contact surface dips 6° or 7° SE. at most other places, but rises sharply east of Pescado Creek. In the vicinity of the divide at the head of Canyon de la Lecheria its strike changes to nearly north and the dip increases to 30° W. The eastward dips in the limestone decrease from 70° to 50°, as they would if the contact surface had been folded. An eastward projection of the base of the limestone would pass above all present outcrops of the quartz diorite.

East of the Piñon Hill fault the contact between granite and quartz diorite dips steeply to the north. Tabular bodies of limestone enclosed in both intrusives are alined parallel to this contact. Neither intrusive sends dikes or salients into, nor holds inclusions of the other. The grain size of the granite commonly is less than that of the normal granite, but this may be related to the upper, not the lateral, margin of the granite.

Quartz Monzonite

Occurrence and Character

The major intrusive rock exposed in the low hills at the southern edge of Antelope Valley is quartz monzonite, part of the large plutonic massif which makes up most of Liebre Mountain. Jointing and brecciation has broken the rock into small fragments and permitted deep weathering. As a result the rock has few outcrops and in general forms rounded slopes with deep soil cover, strewn with small residual boulders, most of them aplitic.

The quartz monzonite is a medium-grained, gray or pink rock with a granitic texture, showing foliation only very locally. In the typical rock both feldspars are white and difficult to distinguish in hand specimen. In some outcrops the potash feldspar is pink, and this color is typical of the microcline in the associated pegmatite and aplite dikes. Biotite is the common ferromagnesian mineral, though hornblende is usually present and in some localities may be the more abundant.

Under the microscope the rock consists of 35 percent microcline, 30 percent plagioclase, 20 to 25 percent quartz, 5 to 10 percent biotite, and 5 percent hornblende. The plagioclase is weakly zoned but remains within the composition limits of andesine, averaging about An_{40}. The crystals are tabular parallel to 010 and show a feeble tendency to parallel the longer axes of the ferromagnesian minerals. Minor amounts of myrmekite are developed at the margins of some of the feldspars, and zoisite has formed long wormlike stringers in the plagioclase. The microcline forms larger crystals than the andesine, and occasionally encloses grains of the latter. Locally it attains a length of 2 centimeters, giving the rock a mildly porphyritic appearance. The quartz is interstitial and all grains have undulatory extinction.

Most of the biotite is fresh, dark green, and strongly pleochroic, though locally it has altered to chlorite. A few zircon grains, surrounded by pleochroic halos, are enclosed in the larger flakes. Hornblende occurs as roughly parallel, dark-green elongate prisms.

Basic Inclusions. Enclosed within the quartz monzonite are dark, irregular masses which range from a few inches to tens of feet across and which are composed of biotite, with lesser plagioclase. They grade fairly sharply into the quartz monzonite and they have a faint foliation parallel to that of the surrounding rock. Although sphene is rare in the normal quartz monzonite it is quite common in the dark rock and in the quartz monzonite adjacent to the inclusions.

These basic bodies may represent fragments of the country rock which have been partially assimilated by the magma or they may be segregations of earlier-crystallized minerals, caught up by the advancing magma. They form less than 1 percent of the outcrops but because they weather more rapidly than the quartzose monzonite they may actually be more abundant than is apparent at the surface. Several prospect pits have been put down on them, but no ore mineral has been found.

Aplite and Pegmatite. Aplite and pegmatite dikes are quite common throughout the quartz monzonite. They range from a few inches to several feet in thickness. The larger pegmatites may be traced for as much as 500 feet; the aplite dikes are less persistent. The two dike rocks are nearly identical in mineral composition, being almost entirely quartz, microcline and oligoclase-albite. They are generally pinkish, owing to the abundance of pink microcline. No mineral deposits are known to be associated with these dike rocks.

Tertiary Rocks

The rocks that probably are of Tertiary age in the Neenach quadrangle include volcanic rocks, consisting of andesite flows and tuff; terrestrial conglomerate, sandstone and shale; marine sandstone and conglomerate of the Santa Margarita formation; and lacustrine deposits. These rocks come to the surface at the west end of Antelope Valley, but do not crop out as far east as the eastern boundary of the quadrangle. The volcanics, marine sediments, and lacustrine deposits lie on an erosion surface of low relief carved on the plutonic rocks. The terrestrial sediments overlie the volcanics. Because of the large amount of faulting, age relationships between the other Tertiary rock units are not directly determinable.

Miocene (?) Volcanic Rocks

Occurrence and Character

Andesite flows and tuff beds are exposed for a distance of nearly 9 miles along the foothills at the south edge of Antelope Valley; they are bounded on the south by the San Andreas fault zone and dip beneath younger sediments on the north, east, and west. They rest unconformably on quartz monzonite.

The unit mapped as volcanic rocks is a thick series of porphyritic and glassy flows with minor amounts of interbedded tuff, agglomerate, sandstone, and limestone. Its thickness is at least 5,000 feet south of Neenach School and apparently less than 1,000 feet just south of La Liebre Ranch, but this thinning may be due in part to elimination of beds by faulting. Dips are mostly to the north at moderate to steep angles, but there is a northwest-trending anticline near the center of the area underlain by volcanics. Erosion of the anticline has exposed the underlying quartz monzonite for a distance of 2½ miles. The basal flows or tuff beds rest directly on a gently rolling surface of quartz monzonite, except very locally where granitic boulders in lenses a few feet thick mark the courses of ancient streams. The position of the old hills of this buried surface correspond to areas of harder, finer-grained quartz monzonite or aplite.

The base of the volcanics in most places is a lenticular layer of white or greenish, sandy tuff or agglomerate, locally 80 feet thick but generally 40 feet or less. Overlying this, five varieties of andesite flows make up the bulk of the volcanic series. These are: (1) green glass and (2) chocolate-red, flow-banded porphyritic rock and flow breccia, which make up the lower part; (3) massive, dark-brown, fine-grained flows, forming the middle of the series; (4) brick-red flows, and (5) black slaggy flows, predominating near the top of the section.

The green glass is strongly flow-banded, the bands are generally much contorted but are locally very regular. The glass is largely devitrified and has a soapy feel. Broken by innumerable curved fractures, it crumbles readily in the hand. No phenocrysts are visible under the hand lens. A typical exposure is shown in the photograph (pl.7*B*).

In hand specimen the fine-grained, massive dark flows are aphanitic, though they contain a few rounded phenocrysts of plagioclase. In thin section the rock is seen to be almost entirely a trachytic swarm of lath-shaped, twinned andesine crystals. Neither quartz nor potash feldspar can be seen, though some may be hidden in the small amount of fine, dusty groundmass. The phenocrysts are resorbed grains of zoned plagioclase, either single crystals or twinned groups. The zoning is normal, extending from labradorite to basic oligoclase, though oscillatory zoning and compositional unconformities of 15 percent are not uncommon. Patches of iron oxide and chlorite have diamond-shaped cross sections, marking the locations of former ferromagnesian crystals, probably hornblende.

The red and black slaggy flows seem to represent the final stage of vulcanism. Though there is little sedimentary material in the underlying layers, these upper flows are interspersed with thin lenses of sandstone, conglomerate, tuff, and limestone, indicating a transition to the overlying sedimentary series. In thin section the brick-red lava is seen to be made up of a few phenocrysts of basic andesine and even fewer of quartz surrounded by a host of andesine laths with trachytic texture. In contrast with the lower flows the groundmass contains much dusty material and patches of devitrified glass; the groundmass feldspars are dark with dusty inclusions. Some quartz occurs in the groundmass, but it may be secondary.

There is not enough quartz in the slaggy flows to class them as dacite, though they are obviously more silicic than the underlying andesite. Some of the tuff beds in the overlying sedimentary series contain abundant quartz, suggesting that the composition of the source magma continued to grow more silicic, though the quartz could of course have been picked up from the underlying quartz monzonite.

Though there are many exposures of the quartz monzonite which underlay the volcanic pile, no dikes were found which could be interpreted as feeders for the ancient lava streams. A few small structures in the lavas indicate that the flows moved northward. The thickest part of the section is south of Neenach School, and this is also the location of glassy flows and thickest basal tuff, which indicates nearness to the source of supply. In the upper part of the section, tuff beds and limestone lenses are more numerous several miles to the west. These would most likely be formed at some distance from the vent, in areas of ponded drainage near the outer ends of lava flows. Closer to the source, relief would be greater and water-laid tuff beds much less likely to be deposited and preserved. The evidence thus suggests the volcanic center was just south of the quadrangle, in a direction southeast of Neenach School.

Age

Evidence from within the Neenach quadrangle indicates only that the volcanic rocks are younger than the Jurassic (?) quartz monzonite and older than the upper Miocene Santa Margarita formation. The fossiliferous marine sandstone and conglomerate of the Santa Margarita formation contain fragments typical of the flow-banded andesite of the volcanic sequence. A few miles west of the quadrangle a thin purplish andesite flow lies at the base of the Santa Margarita, separating it from the underlying granite.

In the Elizabeth Lake quadrangle, Simpson [18] found a few andesite pebbles in marine sandstone and conglomerate of the Martinez formation (Paleocene), and dacitic and basalt flows in Hershey's Escondido formation and in the Rosamond series of late Miocene age. The volcanics in the Neenach quadrangle seem to be conformable with the overlying late Miocene sediments, although the large amount of faulting precludes proof of this. No fossils other than a few poorly preserved rushes were found in the intercalated sediments, and these are valueless for age determination. The meager evidence available suggests that the age of the volcanics is Miocene.

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[18] Simpson, E. C., Geology and mineral resources of the Elizabeth Lake quadrangle, California: California Div. Mines Rept. 30, p. 390, 1934.

Santa Margarita Formation

General Features

Beds of massive marine sandstone and conglomerate containing invertebrate fossils indicative of late Miocene age crop out only at the extreme western edge of Antelope Valley. A wedge-shaped area of 1 square mile is exposed, though an additional area of several square miles probably would be revealed by the removal of a thin cover of terrace gravel and alluvium. The outcrop broadens westward beyond the Neenach quadrangle, extending for nearly 3 miles before it terminates against the San Andreas fault zone. The base of the formation is not exposed within the quadrangle but may be seen 1½ miles farther west, on the east side of Oso Canyon, where fossiliferous sandstone beds lie directly on granite.

In the Neenach quadrangle the exposed part of the formation is entirely white or yellow sandstone and conglomerate made up largely of granitic detritus. Volcanic material is scarce in the lower part of the exposed beds but increases in amount upward, becoming equal to granitic material in the uppermost beds. Dips are moderate or steep to the north and northeast, forming an open northeast-pitching syncline. Exposures are good, but few beds are sufficiently distinctive to be mapped as marker beds.

The sandstone is arkosic, with angular or subrounded grains of feldspar and quartz, some of them fairly coarse, cemented by lime. Thin partings of soft shaly sandstone are fairly common in the lower part of the section. Some sandstone beds, particularly those containing fossils, have enough lime cement to be very resistant to erosion.

In the conglomerate, granite fragments range from small pebbles to subrounded boulders 10 feet in diameter. They are similar to the granitic rocks now cropping out in the mountains a few miles north. The few pebbles of limestone, hornfels, and iron-rich tactite also resemble rock types in the metamorphic terrane to the north, along the granite contact. The volcanic fragments are mainly pebbles of bleached, flow-banded andesite, similar to that occurring at the base of the andesite flows at the south edge of Antelope Valley.

Age

The first mention of marine deposits of an age later than Eocene in the Mojave area was by Merriam,[19] who stated in a footnote that marine beds of middle Tertiary age were discovered on the western border of the Mojave area near Quail Lake. Nolan [20] reported the occurrence of marine upper Miocene rocks on the south slope of the Tehachapi Range at the extreme western end of the Mojave Desert, presumably this area.

Several of the sandstone beds are extremely rich in invertebrate fossil material, but the identifiable species are few. Collections were made

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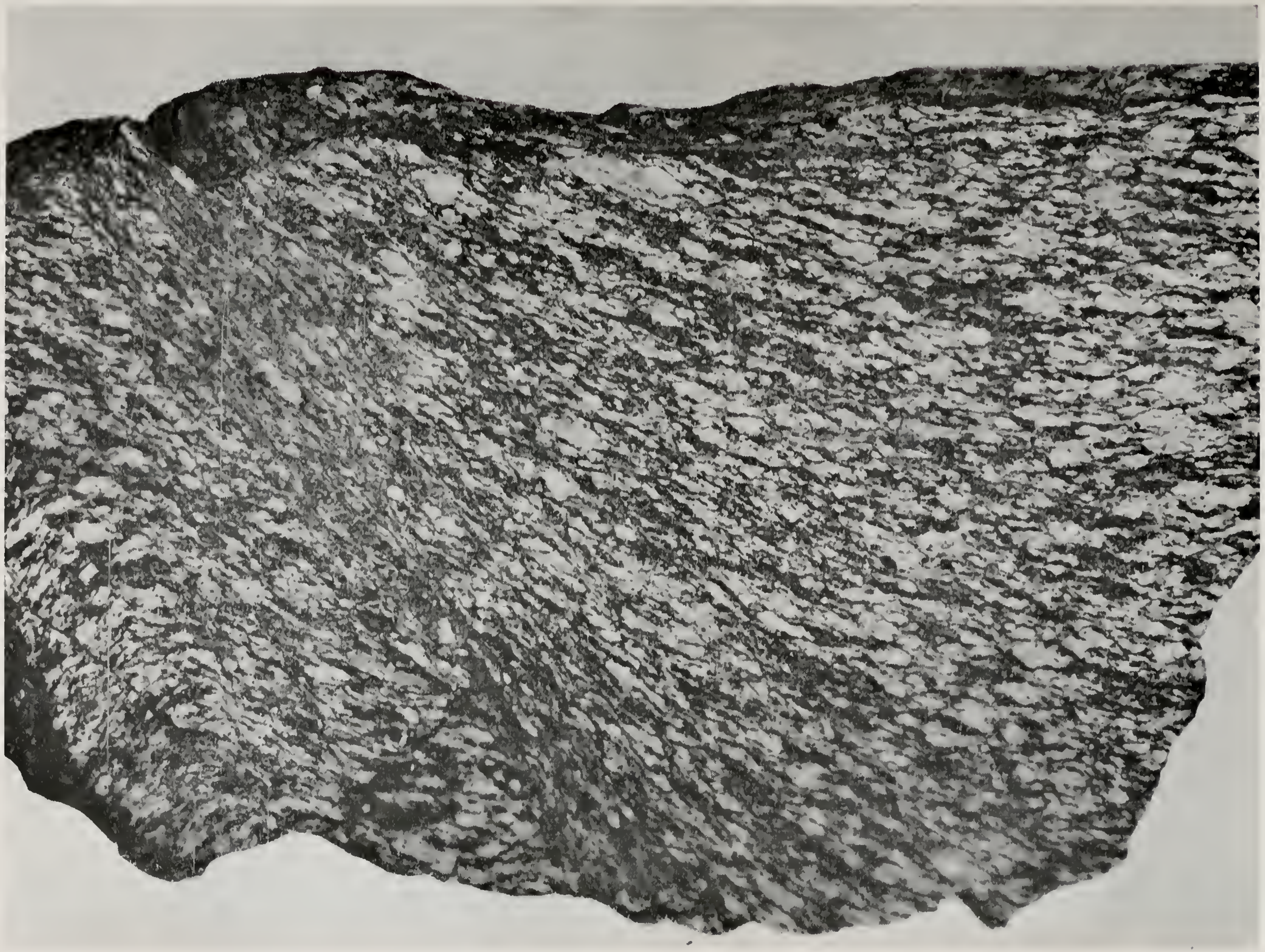
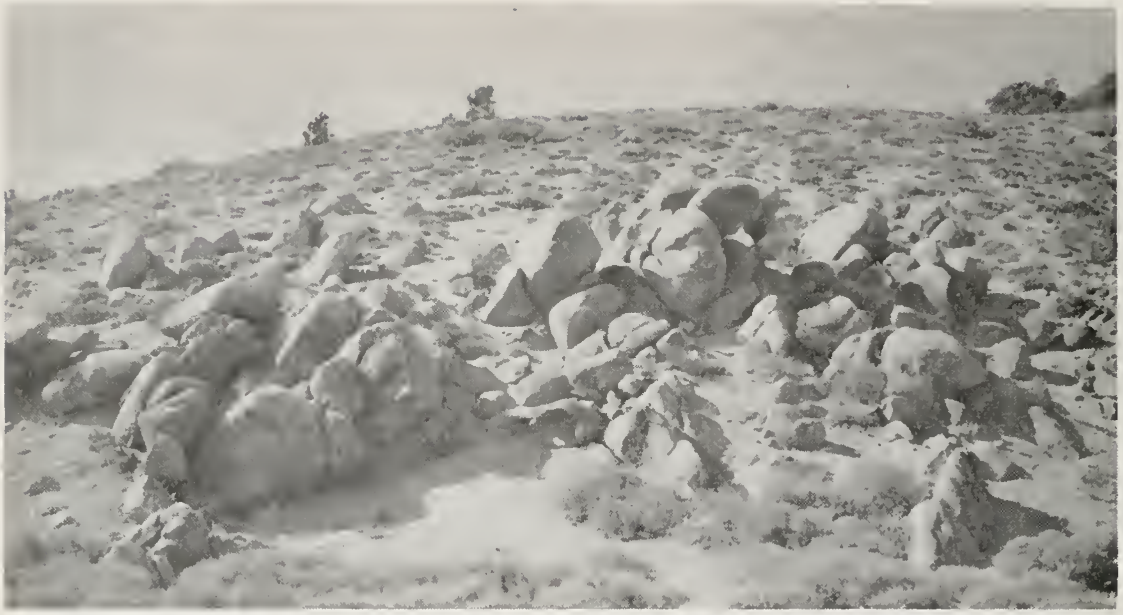
[19] Merriam, J. C., Tertiary mammalian faunas of the Mohave Desert: Univ. California Dept. Geol. Sci. Bull., vol. 20, p. 445, 1919.

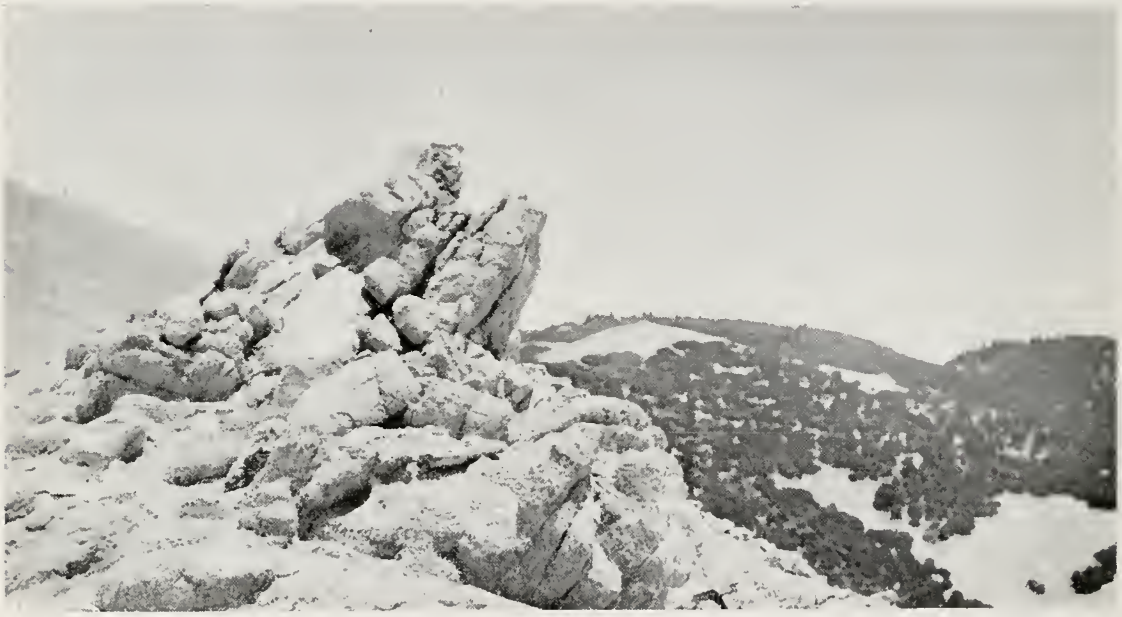
[20] Nolan, T. B., The Basin and Range province in Utah, Nevada, and California: U. S. Geol. Survey Prof. Paper 197, p. 165, 1943.



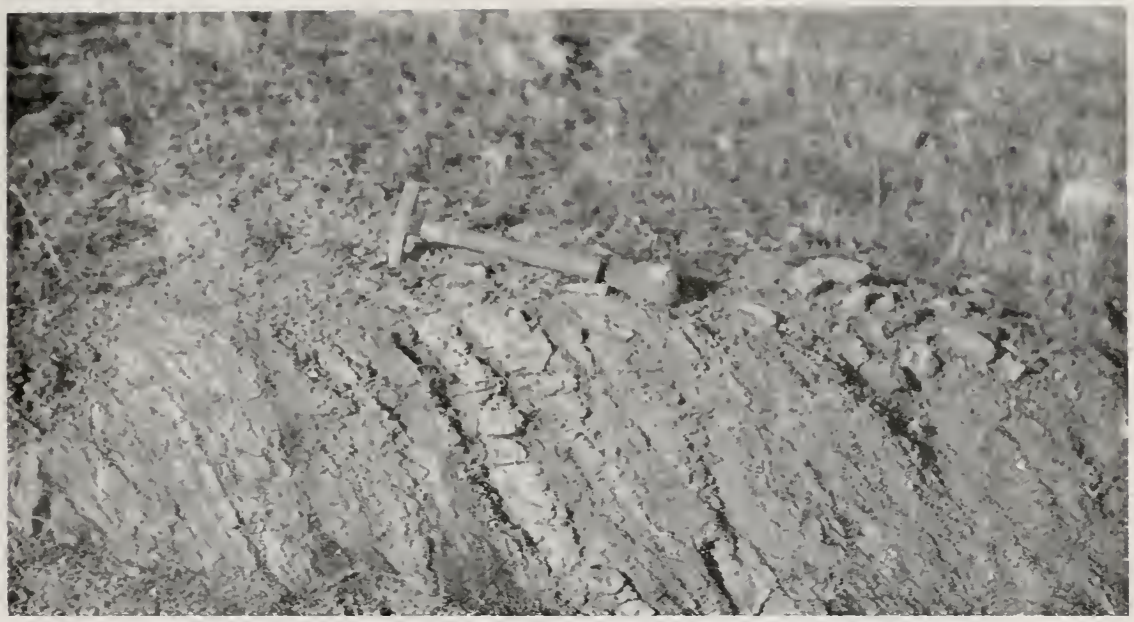
STRONGLY CATACLASTIC QUARTZ-BIOTITE-HORNBLENDE DIORITE
Typical of outcrops north of White Oak Lodge. Mylonite developed along crosscutting shear.



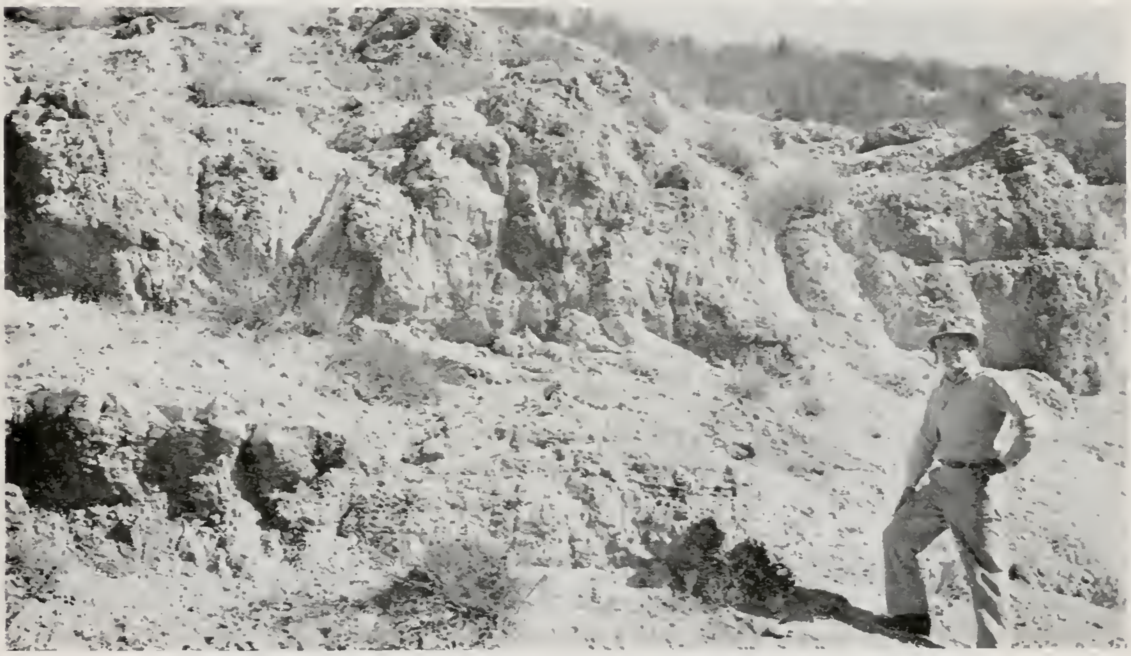
A, TYPICAL OUTCROP OF GRANITE
South of Cluff Ranch.



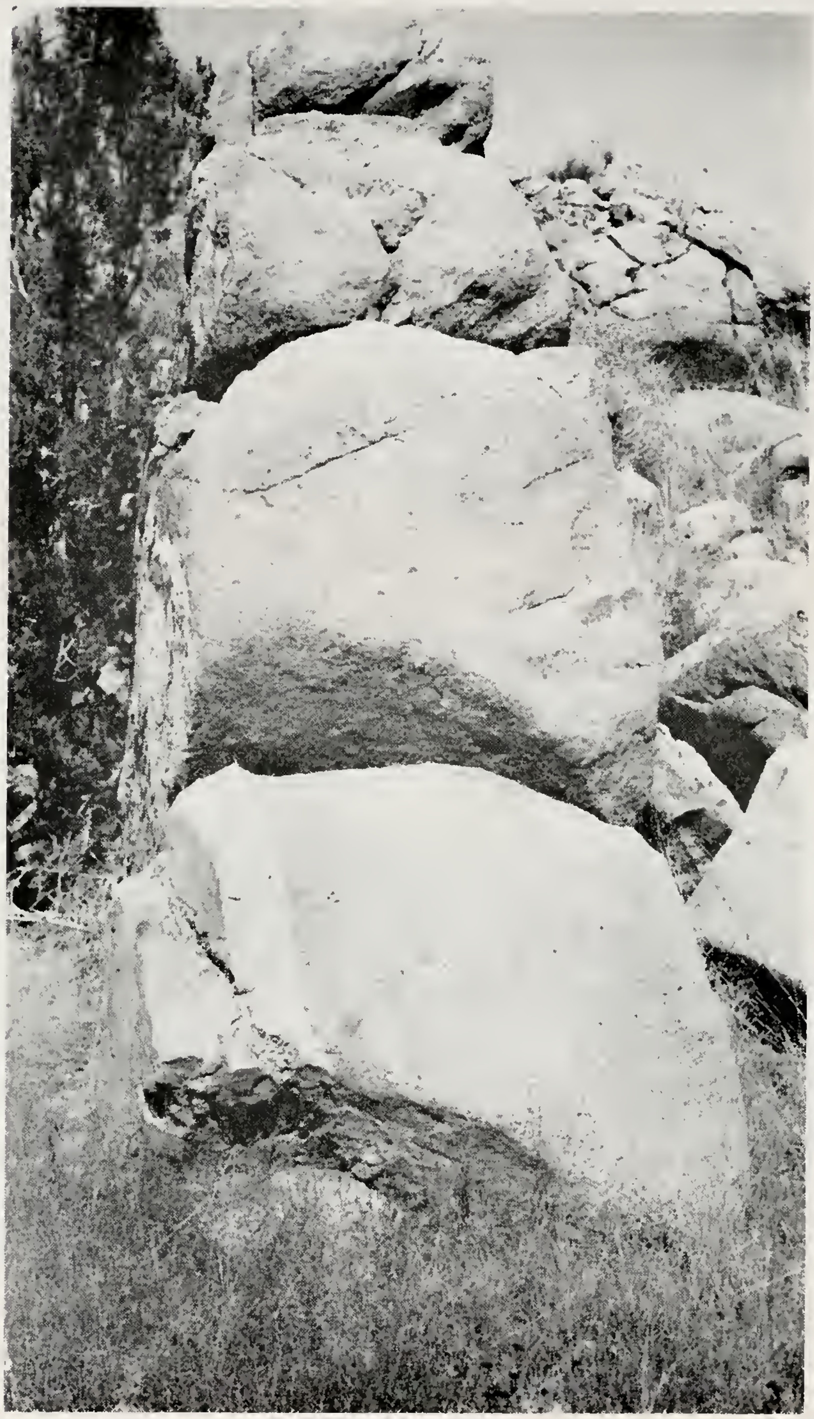
B, BORDER FACIES OF QUARTZ DIORITE
Photo shows crumbly nature of the rock.



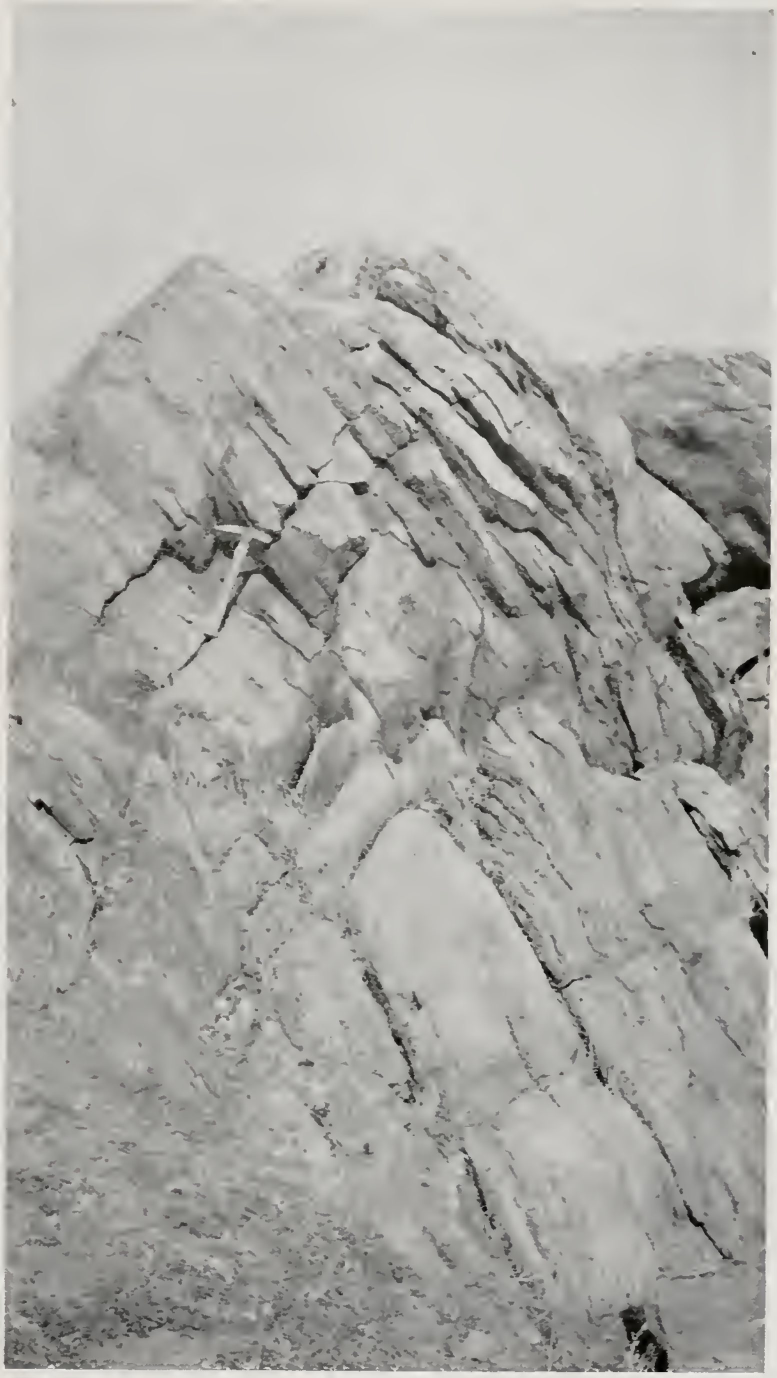
A. INJECTION GNEISS
Pegmatitic quartz and feldspar interlayered with biotite schist.



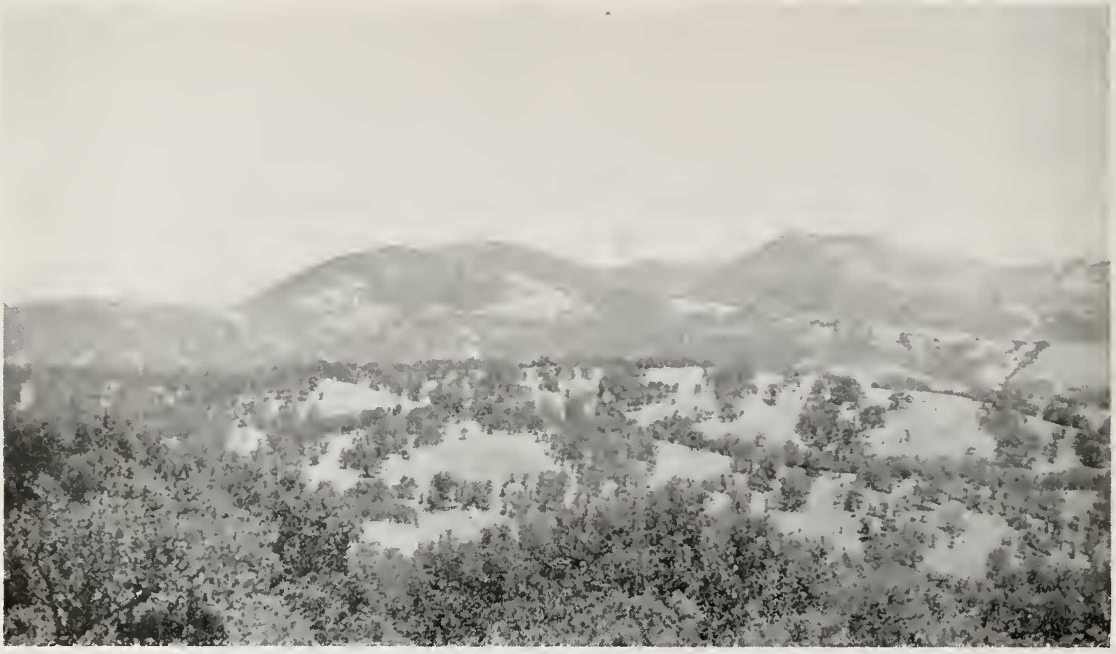
B. FLOW-BANDED GREEN VOLCANIC GLASS
Near base of Miocene (?) volcanic rocks. Banding is nearly horizontal.



QUARTZ MONZONITE
Containing dark inclusions and penetrated by aplite and pegmatite dike.

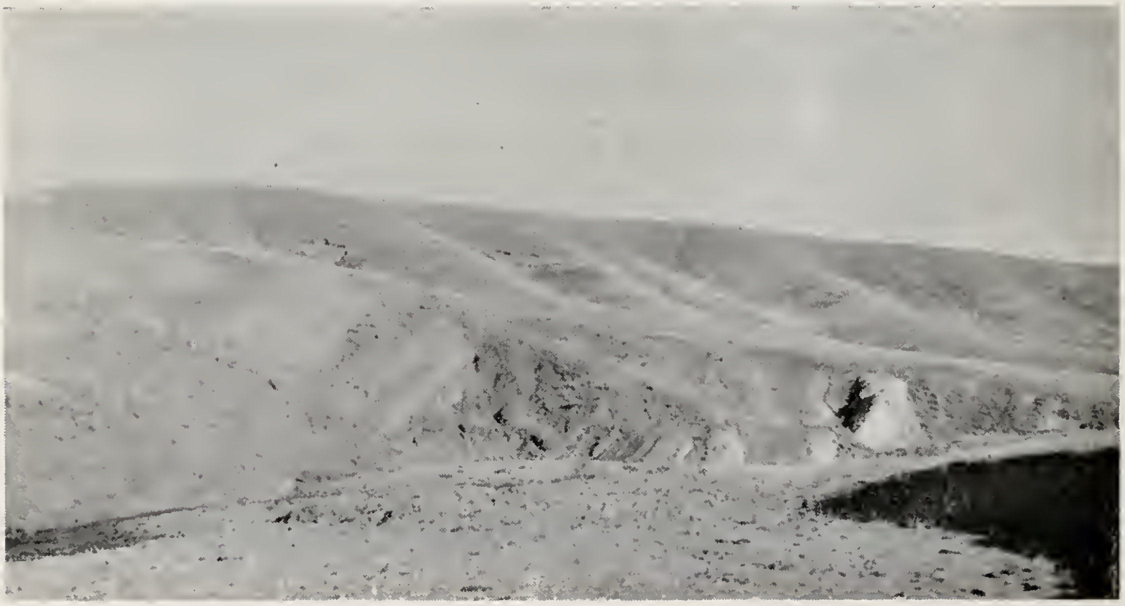


OUTCROP OF INJECTION GNEISS
In northwest corner of quadrangle.



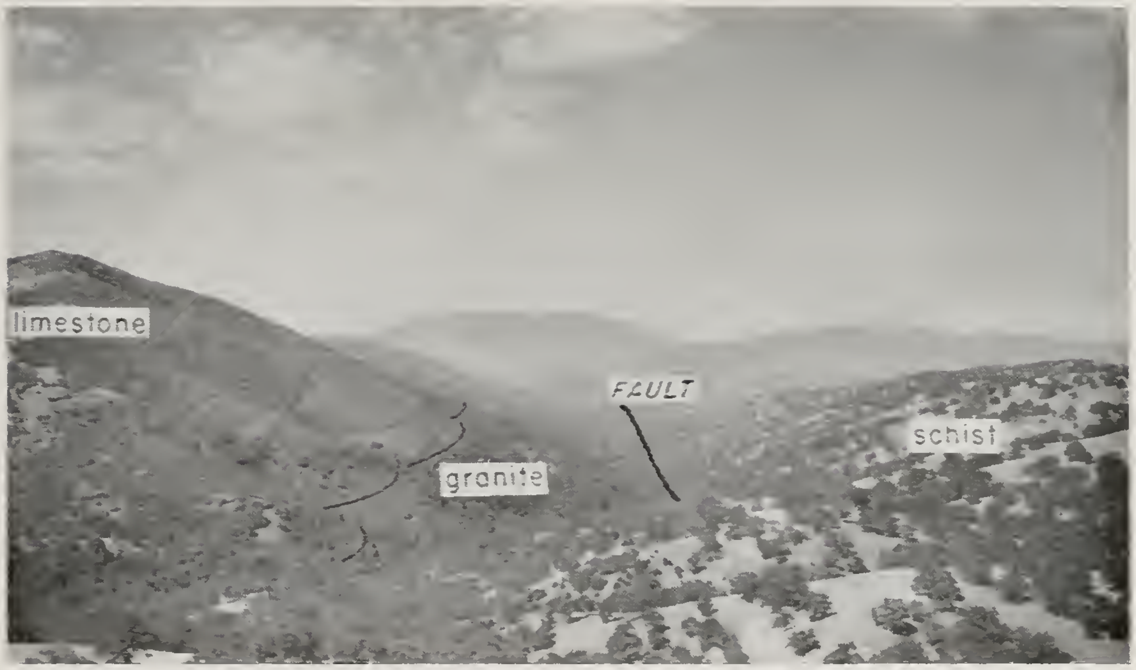
A, EXHUMED PEDIMENT BETWEEN LITTLE SYCAMORE AND BRONCO CANYONS

Flat-lying contact between granite and limestone can be seen midway up mountain in background, at upper limit of heavy brush. View northeast from divide west of Little Sycamore Canyon.

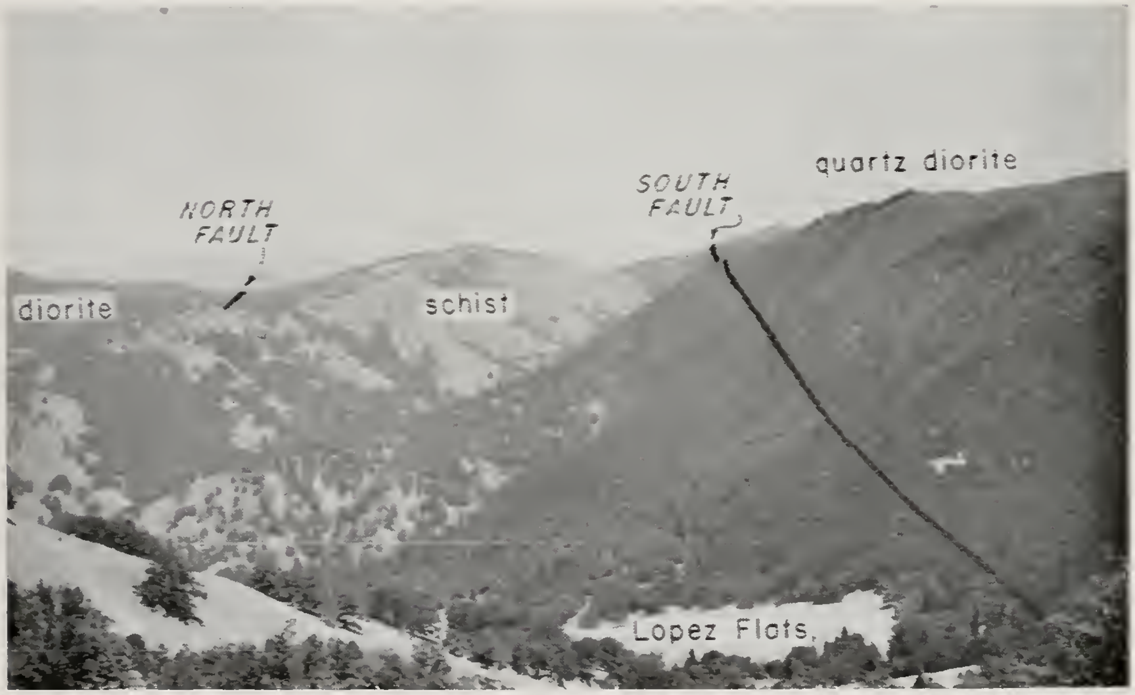


B, RED BEDS IN UPPER UNIT OF MIOCENE (?) CONTINENTAL DEPOSITS

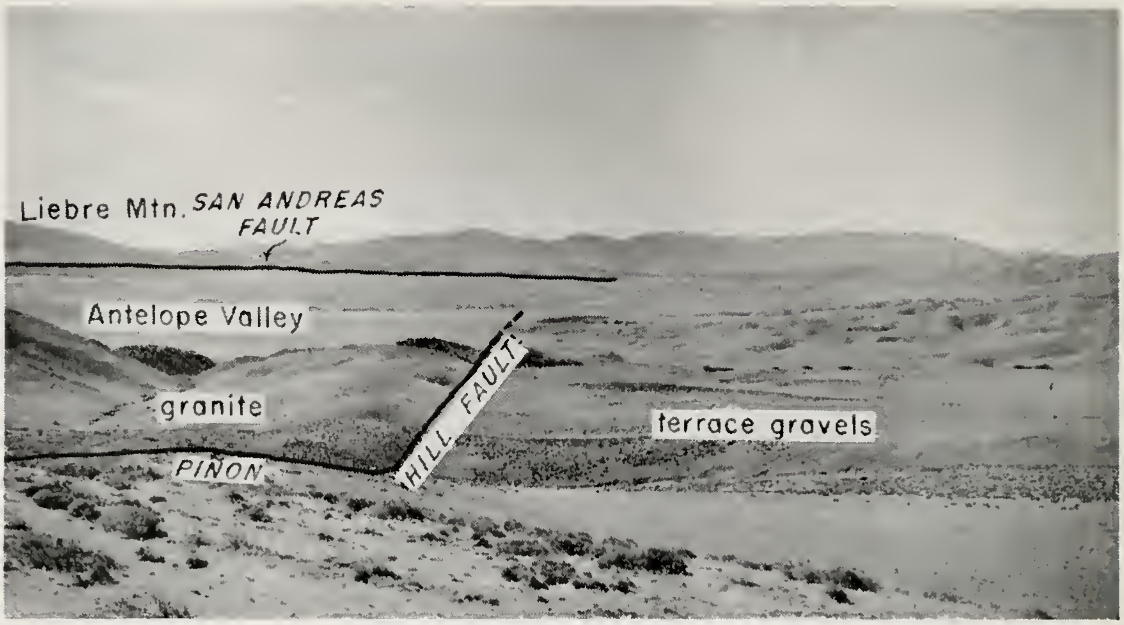
Lenticular cross-bedded sandstone, shale, and conglomerate. Terrace deposits cap ridge in background.



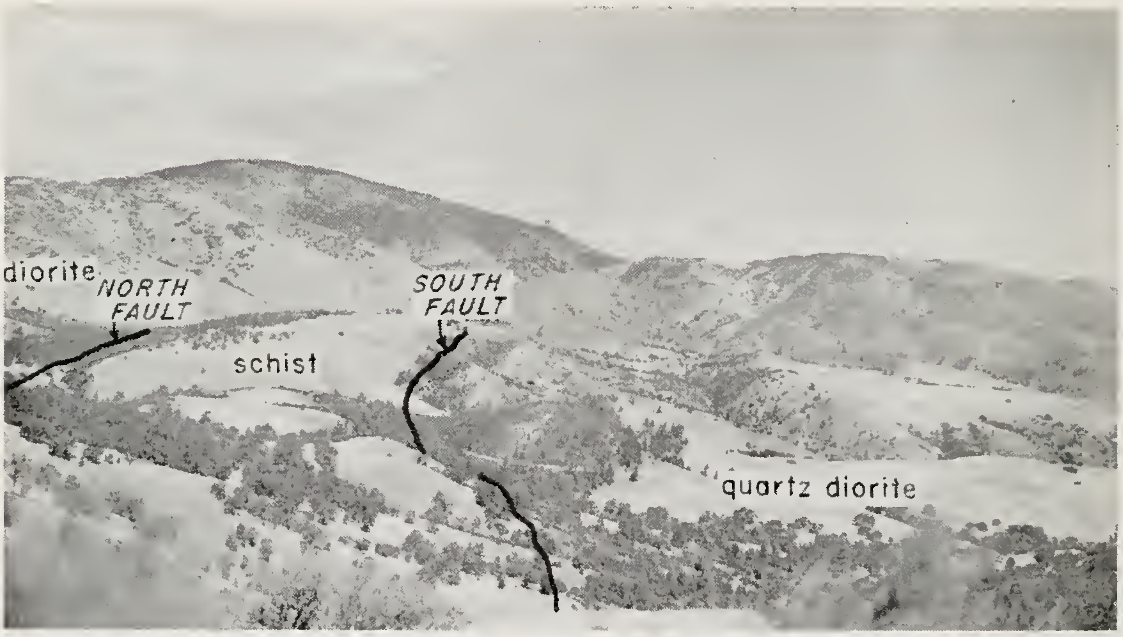
A. VIEW SOUTHWEST FROM HEAD OF BEAR TRAP CANYON
Eroded along south branch of Garlock fault. Pelona schist on right, granite capped by limestone on left. Castac Lake and Frazier Mountain in background.



B. VIEW NORTHWEST FROM DIVIDE BETWEEN TUNIS AND EL PASO CREEKS
Along south branch of Garlock fault. Pelona schist on left, quartz diorite on right. Lopez Flats in foreground.



A, SCARP LONG PIÑON HILL FAULT
Granite on left, terrace gravels on right. Upper Antelope Valley in background. View southwest from ridge 1½ miles south of Sauls Ranch.



B, SOUTH BRANCH OF GARLOCK FAULT
Pelona schist on left, quartz diorite on right. Brushy ridges near center of the photo are limestone slivers along fault zone. View northeast from a point 1 mile north of mouth of Little Oak Canyon.

a few hundred feet within the quadrangle boundary at the north edge of the outcrop of the Santa Margarita strata and at the base of the formation at the east edge of Oso Canyon, near the center of sec. 3, T. 8 N., R. 18 W., about 1½ miles west of the quadrangle. In each place the faunal assemblage is apparently the same, consisting of the following:

Ostrea titan Conrad
Ostrea sp.
Pecten (Lyropecten) estrellanus (Conrad)
Pecten raymondi (?) Clark
Echinarachnius gabbii (Rémond) or *Astrodapsis* sp.
Natica sp.
Shark teeth

Although this assemblage is small, the faunas represented are typical of upper Miocene rocks at the south edge of San Joaquin Valley,[21] and in the Ventura Basin. The lithology of the rock, as well, is strikingly similar to that of the rocks in the Tejon Hills described by Hoots.

The available information indicates strongly that the rocks here mapped as the Santa Margarita formation may be an extension of the Santa Margarita in the San Joaquin Valley. No marine beds of this age are known to the east.[22] That these beds in the Neenach quadrangle were deposited near the eastern limit of the late Miocene seas is suggested by the local derivation of the detritus of which they are composed, their coarseness and shallow-water character and the apparent gradation to continental beds between their outcrop and La Liebre Ranch. The volcanic pile which centers near the latter place may well have been the obstacle preventing a farther landward transgression of the sea.

Miocene (?) Continental Deposits

General Features and Occurrence

A thick sequence of continental sandstone, conglomerate, and shale, probably of Miocene age, underlies much of the southwestern edge of Antelope Valley, and extends eastward from Quail Lake a distance of 10 miles until it is overlain by terrace gravels south of Pecks Ranch.

The sequence is divisible into two units, a lower coarse unit consisting largely of poorly sorted volcanic detritus, which lies conformably on the Miocene (?) volcanic rocks, and is similar to the sedimentary lenses contained within them, and an upper unit made up of red sandstone and shale, with minor amounts of conglomerate. The conglomerate contains a large proportion of granitic material. The contact between the two units is hidden for most of its length by alluvium, in the valley east of Quail Lake. Some red shale is exposed in the faulted area in the low hills just south of this valley. Here the depositional contact between the two units is probably conformable, though the scant evidence afforded by poor exposures is not conclusive.

Lower Unit. Though the lower unit lies conformably on the andesite flows of the volcanic series the conformity apparently is only local, for the sediments are composed primarily of material derived from erosion of the andesite elsewhere. The basal beds are generally purplish volcanic conglomerate as much as 50 feet thick which grades upward through tuffaceous sandstone and shale, with lenses of volcanic conglomerate, to hard arkosic sandstone. The beds vary greatly within short distances along the strike. Thin brownish limestone layers, a fraction of an inch to 6 feet thick, occur at several horizons but do not persist laterally for more than a few hundred feet. Similar limestone layers occur within the andesite and probably represent deposition in small isolated ponds protected from admixture of detrital material.

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[21] Hoots, H. W., Geology and oil resources along the southern border of the San Joaquin Valley, California: U. S. Geol. Survey Bull. 812, p. 273, 1930.

[22] Simpson, op. cit. 391.

Near La Liebre Ranch the base of the section is a thin lenticular layer of buff limestone, an inch to a foot thick, which contains the fresh-water fossils, *Planorbis,* and ostracods. Where the limestone is thickest it is composed of concretionary aggregates which have grown around plant material. Above the limestone layer is a poorly sorted purplish volcanic conglomerate bed 10 to 50 feet thick composed of pebbles of andesite identical with that in the underlying flows and a few rounded pebbles of aplite. Most of the fragments range from 1 centimeter to 3 centimeters across but some are as large as 15 centimeters. Similar beds are also found higher in the section. Above this conglomerate is yellowish-white coarse sandstone alternating with laminated, gray-brown, tuffaceous shale. The sandstone is predominantly of volcanic material but also contains a few percent of granitic detritus. It is tightly cemented with lime and rises above the shale areas as sharp ridges. Ripple-marks, current-scour, and cross bedding are common. No fossils were found in either the sandstone or shale.

Upper Unit. The upper unit of the sequence is mostly interbedded, dark-red, silty sandstone and shale, with minor amounts of conglomerate. Volcanic debris makes up less than a third of the identifiable fragments; the remainder are granitic, mostly aplite and pegmatite. Cross bedding and current-scour in the sandstone and shale, rapid lensing of the conglomerate layers and other features of rapid deposition are common. Many of the cobbles in the conglomerate, particularly those of granitic rocks, are quite well rounded.

Though the red color typical of subaerially deposited sediments is conspicuous throughout this unit, a few conglomerate lenses have a matrix of yellowish-white arkosic sand much the same as that of the Santa Margarita formation. Conglomerate of the latter type is exposed in the cut at the north edge of the highway, half a mile east of the La Liebre Ranch road.

Thickness

No complete section of either unit is exposed, and the lack of key beds permit only tentative correlation between fault blocks. The best estimate of the thickness of the lower unit is a minimum of 3,000 feet. The upper unit must be at least 5,000 feet thick and possibly as much as 8,000 feet.

Correlation with the Santa Margarita Formation

Several facts suggest that the Santa Margarita formation may be correlative with the lower unit of the continental deposits. Just west of the quadrangle, the Santa Margarita formation includes a few hundred feet of chocolate-colored, limy shale about 300 feet above the base. This shale is lithologically identical to that interbedded in the lower part of the Miocene (?) continental sandstone and conglomerate which overlies andesite 1½ miles west of La Liebre Ranch. At the base of the Santa Margarita, where it joins the San Andreas fault zone, a thin purplish andesite flow, lying on granite, is overlain by yellowish arkosic sandstone and conglomerate typical of the Santa Margarita formation in the Neenach quadrangle. It has already been mentioned that this formation lies directly on granite at Oso Creek. The Tejon Oil Company (sec. 13, T. 8 N., R. 18 W.) well cut no red beds or volcanics in 2,163 feet of hole, which may have bottomed in granite.

Possibly, then, the marine sandstone of the Santa Margarita formation is equivalent in age to the lower conglomerate unit of the Miocene (?) continental beds exposed west of La Liebre Ranch. The red beds of the upper unit of the continental deposits may be younger than the Santa Margarita or in part equivalent to it, and down-faulted against it.

Pliocene (?) (Lake Deposits)

General Features and Occurrence

A narrow band of ostracod-bearing, fine-grained sediments crops out along the south flank of the Tehachapi Mountains from the western boundary of the quadrangle to Antelope Canyon, a distance of 8 miles. Though these rocks possibly are equivalent in age to some of the Tertiary formations at the west and south edges of Antelope Valley, they formed under different conditions and have been mapped as a separate unit.

Characteristically the formation is thinly laminated, tuffaceous siltstone, clay, and marl which on wetting breaks down rapidly to mud. Its color may be white, blue gray, greenish gray, orange or brick red. Chocolate-brown concretionary limestone layers a few inches thick are common.

Yellowish sandy beds are interbedded with greenish-gray siltstone at the west edge of the quadrangle and also just west of Antelope Canyon. At the latter locality, the only exposure of the base of the section, the beds rest on granite and dip steeply south. At the contact there is a conglomerate 5 to 10 feet thick made up of rounded boulders, most of which are limestone and tactite, and some of which are granite and aplite. The next 1,600 feet of the section consists of lenticular beds of greenish-gray siltstone, yellowish sand, a few pebble beds, and white tuffaceous marl layers from 6 inches to 3 feet in thickness. The proportion of fine material diminishes upward. At the top the beds are overlain unconformably by terrace gravels which dip 30° S.

Thickness and Distribution

The total thickness of the lake deposits is unknown but is probably several thousand feet. The basal 1,600 feet of the section is exposed just west of Antelope Canyon. The Piñon Hill fault bounds this exposure on the west, offsetting the beds to the mouth of Bronco Canyon, where a thickness of 1,000 feet of red siltstone and marl is exposed, dipping vertically. Between Bronco Canyon and Cottonwood Canyon the lake deposits dip steeply south. A thickness of 1,000 feet of yellow, pink, and gray laminated siltstone and clay can be measured here.

West of Cottonwood Canyon the lake deposits dip steeply south or are overturned. Here the outcrop is bounded by alluvium and terrace deposits, except at the west end where the lake deposits are faulted against the Santa Margarita formation. This section is probably partly repeated by faulting, and though it may approach 5,000 feet in aggregate thickness, an exposure of 700 feet of beds was the longest sequence that could be measured. The rocks are laminated siltstone, clay, and marl, as in most of the exposures west of Bronco Canyon. At the western edge of the quadrangle a few beds of fine yellow sandstone are interbedded with the siltstone. They may constitute a lower part of the section or may indicate approach to the western edge of the basin in which the beds were deposited.

Age and Correlation

Well-preserved, unornamented ostracods, probably fresh-water species, are common in the lake deposits and are the only fossil found, other than carbonized plant remains. The beds are probably younger than the Santa Margarita formation and thus are younger than its probable equivalent, the lower conglomeratic unit of the Miocene (?) continental deposits. They may, however, be equivalent to part of the red beds of the upper unit, and perhaps may represent sedimentation in the center of the drainage basin of that time. The lake deposits are unconformably overlain by terrace deposits, so they are probably older than Quaternary, though this is not proof. The presence of tuff beds, such as are prominent in the Pliocene section to the east, also suggests a Pliocene age for the lacustrine deposits. The great thickness of Pliocene sediments exposed 10 miles south of the Neenach quadrangle is considered to be a lake deposit.[23] Eaton has demonstrated that those sediments are shallow-water deposits, laid down in a slowly subsiding fault trough. Analogous conditions may have existed in the Neenach area during Pliocene time.

Quaternary Deposits

Pleistocene (?) Continental Deposits

Several small blocks of arkosic sandstone, lying on quartz monzonite within the San Andreas fault zone, were mapped as Pleistocene (?) continental deposits. The rocks consist of poorly consolidated, massive, white or orange, silty sandstone interbedded with gray micaceous silt, the product of rapid decay of a granitic terrane, such as that along Liebre Mountain, and deposition under subaerial conditions. The thickness of this unit within the quadrangle is only a few hundred feet. Dips are gentle to steep, becoming vertical next to the faults.

This sandstone extends west of the quadrangle from the San Andreas fault zone to the San Gabriel fault. Eaton [24] included it as part of Division IV of the post-Miocene sediments exposed along the axis of the Ridge Basin syncline, and assigned it to the lower Pleistocene (?) on the basis of vertebrate fossil evidence. No rocks similar to this unit occur elsewhere in the Neenach quadrangle.

Terrace Deposits and Older Alluvium

General Features

The sands, gravels, and clays of the terrace deposits are extremely varied in composition, thickness, and probably in age as well. In general they are deposits of unconsolidated coarse sediments, having a reddish or orange color, to which no further alluvial material is being added at the present. They flank Antelope Valley, lying above all the older rocks and in turn are covered by alluvium on the valleyward side. Their composition varies from place to place depending on the terrane from which the material was derived. The thickness may be only a few feet, as on the foothills between Bronco and Little Sycamore Canyons, or it may be several hundred feet, as near the center of the valley at the eastern boundary of the quadrangle. Their dip is low to moderate, exceeding 25° only very locally. They are of interest chiefly because they record late faulting. The faulting has affected the progress of drainage changes through stream captures.

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[23] Eaton, J. E., Ridge Basin, California: Am. Assoc. Petroleum Geologists Bull., vol. 23, p. 517, 1939.

[24] Op. cit. p. 544.

Distribution

The largest terrace deposit is in the triangular area which flanks the Tehachapi Range from Antelope Canyon east to the edge of the quadrangle. The beds are mostly gravel, though soft red siltstone, sandstone, and clay are common in the lower part. At its upper edge the deposit laps onto a pediment carved on the granitic and metamorphic rocks. It dips gently southeast, and undoubtedly was uplifted by movement along a northeast-trending fault, exposed just east of the quadrangle, which has formed a prominent scarp 400 feet high and 3 miles long.

Near the mouth of Pescado Creek the gravels are down-faulted about 40 feet on the west side of the Piñon Hill fault. From here to the west edge of the quadrangle a basal conglomerate 2 to 10 feet thick, consisting largely of pebbles of limestone and tactite, is generally present. South of the tin mine several tufa layers, each a few feet thick, are included in the gravels which dip 25° NW., toward the mountain, as a result of rotation of the fault block of which they are a part.

At the west end of Antelope Valley, east-dipping terrace gravels, remnants of a mantle which once extended continuously across the valley here, still cover a large portion of the Tertiary sediments. The thickness of the gravels ranges from a few feet to a hundred feet, the thicker portions representing ancient filled valleys.

Terrace gravels in the vicinity of Neenach Ranch are less than 100 feet thick, and dip gently north. Local vertical and south dips are due probably to small-scale faulting. Because much of this land is under cultivation exposures are few, and possibly some sediments mapped elsewhere as Tertiary continental beds are within the areas shown as terrace gravel.

Two areas of older alluvium occur along the Garlock fault zone in the center of the Tehachapi Range. One is Lopez Flats, the other the vicinity of Schamp Ranch. Each exposure is a result of rejuvenation of a stream which probably resulted from the cutting through of a former landslide dam.

Landslides

Two landslide areas have been shown on the accompanying map, and many smaller ones not indicated are present. The two large landslides are along the faulted zone at the south edge of the belt of the Pelona schist. As has already been noted, the schist weathers to micaceous clay which is highly mobile when wet, and when saturated it is capable of movement on even a gentle slope.

At the head of Bear Trap Canyon the schist has flowed northward down Tunis Creek. The brecciated granitic rock south of it, deprived of lateral support, has followed, causing a pronounced bend in the trace of the fault which separates them.

The landslide north of Little Oak Creek is similar, but in this case the direction of movement is toward the south, and the schist has moved outward over the crushed granitic rocks. Owing to movement on the slide, the fault plane, which was formerly almost vertical, now dips 40° toward the mountain.

Younger Alluvium

Areas mapped as Younger Alluvium include all those now receiving stream-borne detrital material—Antelope Valley and the numerous dry washes and creek beds emptying into it. As the valley is bounded largely by granitic hills, granitic detrital material is the largest constituent of the alluvium, which generally consists of ill-sorted white or light-colored sand or gravel.

Recent faulting has offset alluvial deposits in the vicinity of Quail Lake and Bronco Canyon, but elsewhere they appear to be undisturbed. The thickness of unconsolidated deposits beneath Antelope Valley is unknown but is probably large. The Watchhorn No. 1 well, drilled about 2 miles south of the mouth of Bronco Canyon, penetrated 4,150 feet of sediments without reaching basement, but some of this thickness undoubtedly was measured in pre-Quaternary rocks. Another well, 4 miles east of the quadrangle, went through 3,970 feet of sedimentary rock before reaching granite. This latter section may well have been Quaternary rocks exclusively.

STRUCTURAL GEOLOGY

General Character

The Neenach quadrangle contains the western tip of the wedge-shaped salient of the Basin and Range province that lies between the San Andreas and Garlock fault systems. The dominant structures are faults. Folds play a minor role. The wedge-shaped block outlined by the Garlock and San Andreas faults is broken into several narrow, more or less parallel fault blocks of northeast trend. In general these blocks have been tilted to the north, as the north edge of each block has dropped relative to the south edge. Most of the faults, including the San Andreas and Garlock, have steep or vertical dips. Notable exceptions are the small thrust faults in the Tertiary rocks west of La Liebre Ranch and the thrusts in the Paleozoic (?) rocks west of Cottonwood Canyon. Displacements on some of the major faults amounted to miles, and it is fairly certain that movement on several of them, if not on most, had a large strike-slip component.

Repeated movement has probably been the rule rather than the exception, and the history of faulting extends from at least mid-Mesozoic to the present. The epicenter of the Fort Tejon earthquake of 1857 was in this vicinity. At that time a scarp several feet high was formed along the San Andreas fault.[25]

Structural Features

Faults in the Paleozoic (?) Rocks

Two systems of faults which developed prior to the granitic intrusion occur in the Paleozoic (?) rocks. One system strikes northwest and has steep dips; the other consists of south-dipping thrusts. The age relation of these two systems is demonstrated in the vicinity of the tin mine, where two of the steep faults are overridden by thrust plates, thus they were either earlier than the thrusts or contemporaneous with them and confined to intervening plates.

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[25] Lawson, A. C., The geomorphogeny of the Tehachapi Valley system: Univ. California Dept. Geol. Bull., vol. 4, p. 44, 1906.

Available evidence suggests that the whole lower surface of the metasediments, from at least the west edge of the quadrangle to Canyon de la Lecheria, was once the surface of a major thrust fault below which lay more easily stoped or assimiliated rocks. The invading granite locally crossed this lower thrust and reached other, higher thrusts. To a lesser degree it was also guided by the steep faults.

The contact surface between granite and older rocks is nearly a plane and slopes quite evenly 6° to 7° SE. Limestone, quartzite, and calc-hornfels alike are truncated by this surface. Fewer than a dozen small granite dikes penetrate the overlying rocks along more than 25 miles of the igneous contact. In the few localities where beds of schistose mica hornfels abut the granite, they are intimately penetrated by lenticular thin stringers and pods of granite for a distance of a few feet from the contact. In other places bodies of schistose hornfels, a few tens of feet across, similarly injected by granite occur within the granite a few feet from the contact, though the country rock nearby is limestone. It is suggested that these schist blocks on the granite are the last remnants of the footwall block. Further evidence as to the nature of the granite contact will probably be gained by the mapping of its continuation in the next quadrangle to the west, where a larger body of limestone overlies granite.

The thrust planes within the metasediments have the same attitude as the contact discussed above. In general they are marked by bleached zones several tens of feet thick in which all bedding is obliterated, which grade fairly abruptly into the surrounding rock. The upper plate of the thrust just south of the tin mine is brecciated white dolomite-marble which formed the roof of the small cupola of granite there. A similarly situated dolomite caps part of the other cupola of granite a half mile north of the tin mine. The dolomite occurs as a lithologic unit to the west of the quadrangle, at some distance from the granite, and is not to be thought of as the result of alteration along the thrust.

Garlock Fault Zone

In this report the Garlock fault zone is considered to include the two faults that outline the Pelona schist along the center of the Tehachapi Mountains. These faults are major structures. They extend several miles to the east and apparently are continuous with the Garlock fault zone as exposed in the Mojave and Randsburg areas. Seven miles west of the quadrangle they intersect the San Andreas fault zone near Lebec. This fault zone has long been recognized as the Garlock fault and is shown thus on the geologic map of California (1938).

When Simpson mapped short segments of these faults in the Elizabeth Lake Quadrangle he named them the Oak Creek Canyon fault, and considered the recent fault bounding the area of raised alluvium near the center of Antelope Valley, 9 miles south, to be the western extension of the Garlock fault. This recent fault is only one of several smaller faults exposed along the edges of Antelope Valley which are offshoots of the faults here mapped as the Garlock fault zone. It is believed best to preserve the name Garlock fault for the major structure.

The northern fault of the Garlock zone has a straight course and dips vertically or nearly so throughout its length in the area. Exposures along it are poor, but wherever observed the contact is sharp, and there is no mixing of the diorite and schist which form its walls. The narrow zone of metamorphism of the diorite along the fault has already been described. The schist shows no comparable alteration, but is cut by several talcose or sericitic shear zones parallel to the fault.

The south fault dips vertically except where the fault plane has been tilted by landsliding. The contact between schist and granite is sharp; there is no mixing of the two rocks, and the schist seems little affected though the foliation swings to approach tangency immediately at the fault. The adjacent granitic rocks, however, are strongly crushed and sheared, and are cut by closely spaced gouge zones several feet wide for a distance of several hundred feet from the fault.

Discontinuous septa of white and bluish schistose marble form a screen between granitic rocks and schist for nearly half the exposed length of the south fault, and other marble lenses lie along parallel faults within the quartz diorite. These marble bands range in width from less than a foot to a few hundred feet. They resemble the Paleozoic (?) limestone which caps the granite to the south, and are assumed to be slivers dragged into the fault zone.

The crystalline limestone within the quartz diorite on both sides of Cottonwood Creek is less schistose than that along the Garlock, and contains contact-metamorphic silicates, but its contacts with the enclosing rock appear to be faults. These limestone bodies seem to be inclusions which have been oriented and elongated by plastic flowage whereas the enclosing rock, being more brittle, has been brecciated. Limestone caught against the main fault was streaked out to a thin selvage.

Any one of several mechanisms could explain the present position of the limestone in the fault zone. If the ribbons of limestone along the fault from Bear Trap Canyon to Cottonwood Creek were once part of the larger bodies at the latter locality, they could have been caught between schist and granitic rocks and dragged in by lateral movement. Strike-slip movement along the fault in either direction could have resulted in local areas of tension, and a consequent sliverlike graben of limestone. Small later movements would have crushed and erased the other rock types of the graben, but the more plastic limestone would remain. The possibility that at least part of the limestone may belong to the schist series must not be overlooked, nor the chance that there may have been reversal of movement on the fault.

The complete dissimilarity of the rocks on the north and south sides of the fault belt and the presence of the slivers of sheared limestone in the fault make it very probable that the faults are of the strike-slip type. Unless the granite gives way to schist at depth or unless the schist formerly overlay the limestone—both possibilities unlikely—it is difficult to understand how the rocks moved into their present position by any simple combination of post-Jurassic vertical movements; a large lateral component would be required.

The intersections of the faults with structures in the rocks on either side give some suggestions as to the direction of movement. The contact between granite and quartz diorite swings sharply westward as it approaches the south fault near the head of Bear Trap Canyon, indicating, if this curve is to be interpreted partly as a drag effect, that the south block moved relatively east. In the zone of crushed diorite adjacent to the north fault, the foliation becomes tangent to the fault with the acute angle opening west, suggesting, by similar reasoning, that the movement on this fault was relatively westward on the north side.

Hulin [26] found that the Garlock fault offset the margin of a large granitic intrusive a distance of 5 miles in the Randsburg district, with the south block having moved relatively east. Nolan [27] summarizing the work of Hewett, Noble, and others, stated that the late Tertiary movement is dominantly horizontal, with the south side moving eastward a distance of several miles, possibly as much as 25 miles. The results of the present mapping tend to confirm this statement as it applies to the Garlock fault in the Neenach quadrangle.

East of Mojave, 20 miles east of the quadrangle, there is abundant evidence of large movements on the Garlock fault during Pleistocene and Recent time. West of Mojave, in the Elizabeth Lake and Neenach quadrangles, the main Garlock fault zone seems to have been inactive during that time, though movements are recorded on several auxiliary faults, such as the Piñon Hill fault and the fault mapped by Simpson as the Garlock, which branch from the Garlock zone and trend more to the southwest. Possibly this change in locale of the later movements is related to movement along the San Andreas fault zone, against which all the other faults terminate.

Faults Subsidiary to the Garlock Fault

The Garlock has two subsidiary faults, the Piñon Hill fault and the Little Oak Canyon fault. These trend more nearly southwest than the Garlock and cross the foothills of the Tehachapi Range and disappear beneath the alluvium of Antelope Valley. At the south side of the valley faults are exposed which have trends similar to those of the subsidiary faults, and may be related to them. To the northwest, the Piñon Hill and Little Oak Canyon faults approach the south branch of the Garlock fault, but they enter massive granitic rocks and cannot be traced within half a mile of the Garlock.

The Piñon Hill fault must have had a large strike-slip component of movement. It offsets alluvium at the mouth of Bronco Canyon and has formed a small sag pond on the terrace gravels just east of there. The latest movement uplifted the south side about 40 feet, causing a small scarp, still visible on the old fan surface (pl. 12*A*). A gouge zone a hundred feet wide marks the contact between granite and quartz diorite from Canyon de la Lecheria to Cluff Ranch. North of the ranch the fault follows a valley until it is lost in massive quartz diorite.

Distribution of the rocks on both sides of the fault indicates that the major movement has been relatively northeastward on the south side a distance of 2 to 3 miles. The Pliocene (?) lake deposits are offset 3 miles in that direction. The granite east of the fault, northwest of Antelope Canyon, is a distinctive porphyritic rock of finer-than-average grain size, containing large squarish phenocrysts of microcline. This rock is found elsewhere only at the mouth of Little Sycamore Canyon. If the rocks of these two exposures once formed part of the same body, a horizontal displacement of 3 miles is indicated. The contact between granite and quartz diorite is offset 2 miles. As this latter contact dips vertically or steeply north and the contact between lake beds and granite dips south, and both have been offset in the same direction and approximately the same amount, the movement must have been largely lateral.

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[26] Hulin, C. D., Geology and ore deposits of the Randsburg quadrangle, California: California Min. Bur. Bull. 95, p. 62, 1925.

[27] Nolan, T. B., The Basin and Range province in Utah, Nevada, and California: U. S. Geol. Survey Prof. Paper 197, p. 186, 1943.

The base of the limestone on Piñon Hill is very close to where it should be if it is part of the same plane surface at the base of the limestone north of the fault, an indication that there has been little vertical movement on the fault.

The Piñon Hill fault possibly continues southwest beneath alluvium to connect with the fault which limits the south edge of the block of the Santa Margarita formation.

The Little Oak Canyon fault zone is exposed for a distance of 2 miles at the upper edge of the pediment between Cottonwood Creek and Little Oak Canyon. The straight front of the range southwest of the last exposure suggests that the fault continues beneath the terrace deposits at least a mile southwest of Canyon del Secretario. Quartz diorite occupies both sides of the fault though the zone itself contains a sliver of altered white limestone similar to that in the quartz diorite along the south branch of the Garlock fault zone. In a few exposures the fault is marked by a strongly crushed zone at least 50 feet wide in which the rock has been ground to soft limy powder containing only a few lenticular chips an inch or so thick, still recognizable as igneous rock.

The presence of a large block of limestone and hornfels in the south block, much larger than any inclusion in the north block, may mean that the south side of the fault has dropped, as larger inclusions or roof pendants generally are found in the upper part of a batholithic intrusive. The sliver of limestone along the fault, however, suggests that the fault is comparable to the Garlock, and may have had largely strike-slip movement.

San Andreas Fault Zone

Along the 4-mile segment of the San Andreas fault zone included in the southwest corner of the quadrangle, granitic rocks lie against Miocene (?) volcanics and sedimentary deposits. Features of the fault zone here are similar to those along it elsewhere.[28] The zone is half a mile wide, and is made up of several interlacing faults of steep dip which outline long narrow slivers of granitic and sedimentary rock. The granitic rocks are greatly crushed and are eroded readily. The debris contributes to small landslides which obscure any recent fault scarps. Quail Lake probably owes its origin to recent movement on the San Andreas.

Little evidence is available within the quadrangle as to the maximum movement on the San Andreas fault. The apparent net vertical component since the Miocene is at least several thousand feet, with the north side moving relatively downward. However, the Pleistocene (?) arkosic sandstone involved in the fault zone in the area, and which underlies a large territory to the south of the San Andreas immediately west of the quadrangle, has no counterpart north of the San Andreas. Either the continuation of these rocks north of the San Andreas was upfaulted and eroded, or the rocks were brought to their present position by large lateral movement. The fault pattern north of the San Andreas is suggestive of strike-slip movement of that block to the southeast, for the subsidiary faults bend to the west as they approach the San Andreas.

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[28] Noble, L. F., The San Andreas rift and some other active faults in the desert region of southeastern California: Carnegie Inst. Washington Pub., Yearbook 25, pp. 415-428, 1926.

Faults Subsidiary to the San Andreas Fault

Several faults displace the Tertiary rocks in a band about 4 miles broad along the northeast side of the San Andreas. Nearly all of them are high-angle faults and trend northeast. A few folds associated with the faults also trend northeast. In general the number and complexity of faults and folds increases toward the San Andreas. This concentration makes it seem likely that the structures are related to adjustments along the San Andreas, but their orientation suggests that at least some of them were localized by the presence, in the basement, of pre-Miocene faults that are subsidiary to the Garlock.

A half mile east of La Liebre Ranch a vertical fault contact between quartz monzonite and andesite can be traced southwest for nearly 3,000 feet. At the west edge of the creek 1 mile east of the ranch, a smaller mass of quartz monzonite is faulted against andesite. Elsewhere, Tertiary rocks, largely volcanics, lie on both sides of the fault. It extends for 3 miles, from the San Andreas to Antelope Valley, and probably continues some distance northeast beneath alluvium. The base of the andesite is downthrown 2,000 feet on the south side. This fault probably began in pre-volcanic times, for the quartz monzonite is strongly brecciated and sheared, whereas the equally brittle volcanic rocks against it are not.

A small overthrust 1 mile southwest of La Liebre Ranch brings a plate of volcanics above overturned continental deposits. The fault dips gently southwest and probably continues in that direction to the San Andreas. Displacement along the thrust was at least a few thousand feet.

The contact between volcanics and continental beds from a point north of La Liebre Ranch eastward to south of Neenach School also may be an overthrust dipping south. The stratigraphic displacement would be small, for beds typical of the basal part of the sediments lie immediately north of the contact.

Alluvium and terrace deposits, about 3 miles east of Quail Lake, largely conceal the two northeast-striking faults which probably extend from the San Andreas fault zone to Antelope Valley. Structures of the rocks between them and a half mile on both sides are much more complex than can be shown on the present scale map. Several branches of the south fault were mapped; concealed ones undoubtedly exist. About a mile northwest of La Liebre Ranch the south fault bounds the northwest edge of a small plate of sediments thrust southeast over several tight folds. The direction of movement on the south fault is relatively down on the north, probably more than 1,000 feet. Movement on the north fault is unknown. Both faults could have been strike-slip.

Another steep fault of northeast trend crops out half a mile north of Quail Lake, where it limits the Santa Margarita formation on the south. The fault must bound this formation for several miles to the northeast, and may join the Piñon Hill fault beneath the alluvium there. The south side apparently was downthrown at least 2,500 feet since the Miocene, but no estimate of the actual movement is possible. Within the quadrangle, movement since the terrace deposits were laid down occurred only at the extreme west edge of the quadrangle, where the south block is downfaulted a few tens of feet.

The north limit of the Santa Margarita formation is a fault trending slightly south of east, which brings the Pliocene (?) lake deposits down against the Miocene rocks. The massive sandstones of the Santa Margarita increase in dip as they approach the fault and become vertical or overturned against it, suggesting that the displacement, which apparently is measured in thousands of feet, was largely dip-slip and that the fault dips steeply to the south. This fault ends, about 4,000 feet west of the quadrangle against a steep fault of northeast strike which enters the quadrangle along the front of the Tehachapi Range and is the contact between Paleozoic (?) limestone and Pliocene (?) lake deposits half a mile south of the tin mine. Alluvium conceals the trace of this latter fault within the quadrangle. The apparent vertical displacement is large, probably several thousand feet. One mile west of the area, where it offsets the base of the Santa Margarita formation, the south side moved down and eastward a distance of at least several thousand feet.

PHYSIOGRAPHY

Two striking geomorphic features of the southwest end of the Tehachapi Range are apparent. One is the strong asymmetry of the range, for nearly three-fourths of the range is north of the crest; the other is the influence of the Garlock fault zone on the development of the drainage pattern.

The asymmetry is largely, if not wholly, the reflection of the difference in base level on each side. The San Joaquin Valley is less than 1,500 feet above sea level where it fringes the northern edge of the range. On the south side, the mountains meet Antelope Valley at altitudes ranging from 3,200 to 3,500 feet. As the gradients of the streams on both slopes are approximately the same, the crest must lie nearer the higher valley.

The Garlock faults have brought a band of one of the least resistant rocks in the quandrangle, the Pelona schist, into the center of the Tehachapi Mountains. The presence of this rock has permitted the rapid downcutting of the headwaters of many of the streams draining the north slope and encouraged the establishment of subsequent drainage along the Garlock faults. Pastoria, Tunis, and El Paso Creeks follow the northwest strike of the foliation in the gneiss, gabbro, and diorite in their lower reaches, but branch out into northeast-southwest tributaries where they head in the schist. On the south slope, tributaries of Cottonwood Creek follow the same pattern.

Topographic features of the south slope of the Tehachapi Mountains are largely related to the distribution of the limestone, the rock most resistant to erosion. The limestone inclusions along the toe of the range between Antelope Canyon and Little Oak Canyon support a screen of outlying hills which mask the presence of several large valleys carved in the less resistant marginal facies of the quartz diorite, valleys such as Canada del Agua Escondida and Canyon del Secretario.

All the stream valleys of the south slope of the range between Bronco Canyon and Little Oak Canyon curve to the right as they emerge onto the alluvial fans which flank the range. This deflection is a result of the doming of the fans on an axis which trends south-southeast from a point a quarter of a mile east of the mouth of Little Oak Canyon. The result of this arching is that the surface of the fans, which once dipped southeast, now slopes only slightly east of south, and the streams, though held to their former beds in the mountains, must change their courses to the south as they emerge from the foothills in order to follow the steepest gradient.

The remnants of at least two older surfaces of erosion record the late history of the Tehachapi Range. The earlier surface was most widespread, and extended to what was probably the crest of the range at the heads of Cottonwood, Little Sycamore, and Big Sycamore Canyons. No recognizable remnants occur on the north slope. On the south slope various parts of this surface have been affected only moderately by later erosion, as, for example, the sharply defined plateau about 1,000 feet wide and half a mile long at the head of Little Sycamore Canyon, the smooth slope on the limestone northeast of the tin mine, and the pediment which fringes the limestone mountain northeast of Quinn Ranch. This surface of erosion was of very low relief, and the lower part probably was overlain by a mantle of gravel. The consequent drainage pattern established by a lowering of base level is now superimposed on the underlying granite, as shown by the direct courses of all the major streams from Cottonwood Canyon to Canyon de la Lecheria. There is an abrupt change to a dendritic pattern northwest of a line between Quinn Ranch and the point where the 3,900-foot contour crosses Cottonwood Canyon, and this line may be the upper limit of the gravels on the old surface.

The gravel-covered pediment carved across the Tertiary beds at the southwest edge of Antelope Valley is probably younger than the surface described above, and equivalent in age to the domed pediment along the range from Antelope Canyon eastward. The dissection of this surface was caused by the doming and lowering of base level by downfaulting of that part of Antelope Valley lying immediately east of the quadrangle.

MINERAL RESOURCES

Though the mountainous area within the Neenach quadrangle has been prospected for perhaps a century, few mineral deposits of value have been discovered. Colors of gold may be obtained by panning the granitic gravels on the slopes of Liebre Mountain at the south edge of the quadrangle, and small gossan bodies, reported to contain traces of gold, are fairly common along the south slope of the Tehachapi Mountains. Three workings near the southeast corner of the quadrangle produced a few hundred thousand dollars worth of gold during the middle 1930's.

The discovery of tin in 1942 revived interest in the district, especially around the margins of the limestone at the west edge of the quadrangle. Several small deposits were found; a few tons of ore was produced, but work on them ceased in 1945.

Two unsuccessful borings for petroleum were made at the west end of Antelope Valley about 1920; none has been attempted since then.

Tin

General Features and Production

The geology of the immediate areas of the tin deposits has been described in detail[29] and is only summarized here. Four deposits are known in the Neenach quadrangle, all of them lying at or near the margin of the limestone west of Cottonwood Canyon. Two other deposits are in the adjacent quadrangle, about 2 miles southwest. All production has come from the Meeke mine, designated "Tin Mine" on the accompanying map.

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[29] Wiese, J. H., and Page, L. R., Tin deposits of the Gorman district, Kern County, California: California Div. Mines Rept. 42, pp. 31-52, 1946.

The ore bodies are small, though in part high-grade, replacement bodies in limestone, either at the margin of the granite or within a few hundred feet of it. Cassiterite occurs in the primary ore along with scheelite, pyrite, magnetite, chalcopyrite, arsenopyrite, molybdenite, epidote, tourmaline, ludwigite, amphibole, garnet, mica, calcite, and quartz, though not all these minerals occur in each deposit. As a result of secondary alteration the sulfides have been changed to hydrated iron oxides associated with malachite, chrysocolla, jarosite, powellite, gypsum, chalcedony, opal, and clay minerals. The magnetite is in part altered to hematite, and the amphibole is altered to chlorite.

The Meeke mine is by far the largest deposit. Here, irregular short veinlets and small masses of granular cassiterite, closely associated with scheelite, molybdenite, tourmaline, and mica, replace parts of a limestone bed over a length of 250 feet and a width of 40 feet. The limestone bed is overlain by hornfels and quartzite, and is faulted off at both ends. After the tin mineralization, a large part of the limestone bed in this same block was replaced by pyrite, so at the present time the cassiterite occurs partly in limestone, partly in massive pyrite, and partly in the limonitic, silicified gossan resulting from alteration of the pyrite. There are two mineralized zones which might be called ore bodies. They are at each end of the limestone bed and are more or less tabular, dipping with the bedding at angles of 20° to 40° N. The results of core-drilling indicate that the west ore body, the larger, pinches out about 150 feet down the dip and that the eastern body extends only to a depth of a few tens of feet.

The other deposits, the Upper and Lower Butler and the Gray Eagle, are smaller than the Meeke and less well known. All are iron-rich replacement bodies in limestone, lying directly on the contact between granite and limestone. They have a larger percentage of silicate minerals and the cassiterite is finely divided. They contain no high-grade pockets such as are found at the Meeke deposit.

The high-grade ore gathered for shipment from the Meeke deposit was mostly from residual boulders exposed at the surface, though some of it came from shallow pits on pockets in limestone. Production consisted of three shipments, as indicated in table 1. Because of the small amount of impurities, the ore brought a premium price.

Table 1. Tin production,[a] *Gorman District, Kern County, California*

Date	Tons [b]	Percent Sn	Impurities
May 1943	3.5	35.65	
May 1944	1.4	48.90	S 0.26, Pb 0.03, Sb 0.06, As 0.20, Bi 0.01, Cu 0.05, Zn 0.05.
August 1945	1.8	39.44	S 0.85, Pb 0.05, Sb 0.10, As 0.28, Bi 0.02, Cu 0.06, Zn 0.30.

[a] Sold to Metals Reserve Company, Fresno, California.

[b] Tonnage figures in this paper are in short tons.

Exploratory work in 1944 by the U. S. Geological Survey and U. S. Bureau of Mines resulted in the following estimate of reserves for the entire district:

Table 2. Reserves of tin ore, Gorman District, Kern County, California

Type of ore	Percent Sn	Tons	Type of ore	lbs. Sn /cu. yd.	Cu. yds.
Ore in place	1.0 to 2.0	3,740	Placer dirt	15-30	800
"	0.5 to 1.0	3,450	"	3-15	2,460
"	0.1 to 0.3	25,600	"	1.5	10,000

Suggestions for Further Prospecting

The present study has proved that the tin mineralization is related genetically to the granite, and that search for tin outside the area underlain by granite will be fruitless. In addition, tin ore is found only at or within a few hundred feet of the contacts of limestone and granite, so the search should center along those contacts, especially where there are upward bulges of the granite, expressed either as embayments in the edge of limestone outcrop or as small isolated exposures of granite surrounded by limestone.

Fault contacts of granite and limestone will be unproductive, as the tin deposits formed before the faulting and are not related to it. Older faults within the limestone, however, guided the entrance of granite and the tin-bearing solutions, so they are especially favorable places to prospect.

The terrace gravels crossed by the 3,800-foot contour at the east edge of Big Sycamore Canyon contain magnetite-rich pebbles, tin-bearing ludwigite, and cassiterite. Cassiterite panned from the nearby washes comes from this terrace deposit and does not signify the presence of an ore deposit. The source of the tin-bearing gravel has not been discovered.

Gold

Gold has been produced from only one property in the Neenach quadrangle, the Rivera Mining Company mines at the southeast corner. The discovery of this deposit by W. J. Rogers about 1934, coupled with the finding of the rich Silver Queen mine near Mojave in the same year, led to a small gold rush. Many claims were staked and hundreds of pits put down in the foothills on both sides of Antelope Valley, but no other ore bodies were discovered.

The Rivera mine area, consisting of the Rogers-Gentry, Myler, and Tuttle mines, is reported to have produced about $200,000 in the few years following its discovery. Little work has been done since 1937, and in 1946 all the properties were idle. The ground is highly faulted and difficult to support, and all workings in ore are now inaccessible. All the workings are shallow; the deepest extend only a few hundred feet in depth. The gold occurs in quartz, with more or less pyrite and other sulfides, along the contact between quartz monzonite and metasediments. The ore had an average value of $40 to $50 per ton.[30]

At the east end of Piñon Hill, half a mile south of the Cluff Ranch, several small limonite gossan bodies were explored in 1941 by the Piñon Hill Mining Company. The gossans were formed from the alteration of massive pyrite bodies which replaced limestone at the edge of the granite. No production is recorded, though a few samples are reported to contain gold values as high as $20 per ton.

Other Metals

Small limonite gossan bodies a few feet across occur in many places in the limestone. Some contain a few specks of green copper minerals and others a few crystals of scheelite and powellite. Most of them have been explored by shallow pits, open cuts or short adits, but none seems to have warranted further work.

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[30] Tucker, W. B., Current mining activity in southern California: California Div. Mines Rept. 30, p. 319, 1934.

The two largest scheelite prospects are at the end of a dirt road, 6,000 feet N. 70° E. of Cluff Ranch and on a ridge 4,000 feet S. 20° E. of the house at the head of Canyon del Secretario. Neither appears to have had any production. They explore small garnet-rich tactite bodies at the edge of limestone inclusions which probably extend downward only a few tens of feet.

Molybdenite occurs in a pegmatite dike in gneiss on the ridge north of Tunis Creek, but is of no economic value. Manganese silicate, largely altered to black oxides, replaces part of a boulder of Pelona schist several feet in diameter at the upper edge of the terrace deposit half a mile northeast of the mouth of Little Oak Canyon. No similar manganiferous schist was found in place.

Marble and Limestone

There are two quarries from which marble for building stone has been taken. One is on the granite contact at the east edge of Pescado Creek and the other lies 1,000 feet northeast of Cluff Ranch. The Pescado Creek quarry was first worked before 1900, and is said to have furnished pink sugary marble for several buildings in Los Angeles and San Francisco. It has been idle for many years.[31] The Cluff Ranch quarry yields white sugary massive marble, locally coursed by narrow veinlets of greenish silicate minerals. It also has been idle many years.

A large amount of crystalline limestone is contained in the Paleozoic (?) rocks but the relative inaccessibility of the areas has prevented exploitation. Some beds above Quinn Ranch are tens of feet thick and contain few impurities other than a few flakes of graphite. Others are interlayered with hornfels and quartzite. There is little or no overburden.

Crushed Rock

A number of small quarries were opened along the eastern edges of Antelope Valley to furnish crushed rock for the construction of the Los Angeles Aqueduct. Limestone, granite, andesite, and quartz monzonite were used. All the quarries are now idle.

Volcanic Ash

The white tuff layer at the base of the andesite flows is variable in thickness and purity. In the creek bottom half a mile east of La Liebre Ranch it is altered to yellowish-white bentonitic clay containing little admixed sand, and it is about 30 feet thick. It is exposed along the strike for about a hundred feet, dipping steeply north. Some of the clay has been used as hydraulic pump lubricant and grouting seal. Since the pit was abandoned the creek has spread a new mantle of sand and gravel over the deposit.

Petroleum

Two holes were put down in search of petroleum about 1920. Both were drilled with cable tools and the records of the formations penetrated are not very informative. Tejon Ranch Oil Company well No. 1 is in sec. 13, T. 8 N., R. 18 W., at the west edge of the quadrangle. The hole passed through ''blue and brown sand and shale'' to a depth of 2,163 feet, bottoming in ''sand and boulders,'' according to the driller's log. Whether or not the hole reached granite cannot be determined from the record. The driller's log lists "tar sand" from 646 to 648 feet and from 1,275 to 1,276 feet.

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[31] Tucker, W. B., Los Angeles field division—Kern County: California Div. Mines and Mining Rept. 25, p. 73, 1929.

About the same time the Robert Watchhorn well No. 1 was drilled to 4,150 feet in sec. 27, T. 9 N., R. 17 W., about 6 miles to the northeast of Tejon No. 1. It apparently did not reach basement.[32] A strong flow of warm fresh water was encountered from 4,062 to 4,078 feet.

The only marine sedimentary rock of Tertiary age is the Santa Margarita formation, which probably extends only a few miles into the western part of the quadrangle. No showings of gas or oil were seen at the outcrop or obtained in the deep water wells of the area, and it is unlikely that petroleum or gas exists at depth.

Ground Water

Water for domestic and stock use has long been obtained from shallow wells and springs at the margins of Antelope Valley. In 1946 six deep wells were drilled to obtain water for the irrigation of crops, mainly potatoes.

Three wells near the center of Antelope Valley, north of La Liebre Ranch, went to depths of 700 to 800 feet, but the largest water supply came from a depth of 400 to 500 feet. Standing water rises in them to within 100 feet of the surface. During the summer of 1946 each well was pumped continuously at a rate of about 1,000 g.p.m. Three other wells within a radius of 1 mile, west and southwest of Pecks Ranch reached depths of 860, 1,033, and 900 feet. The water-bearing sand was found below 400 feet.

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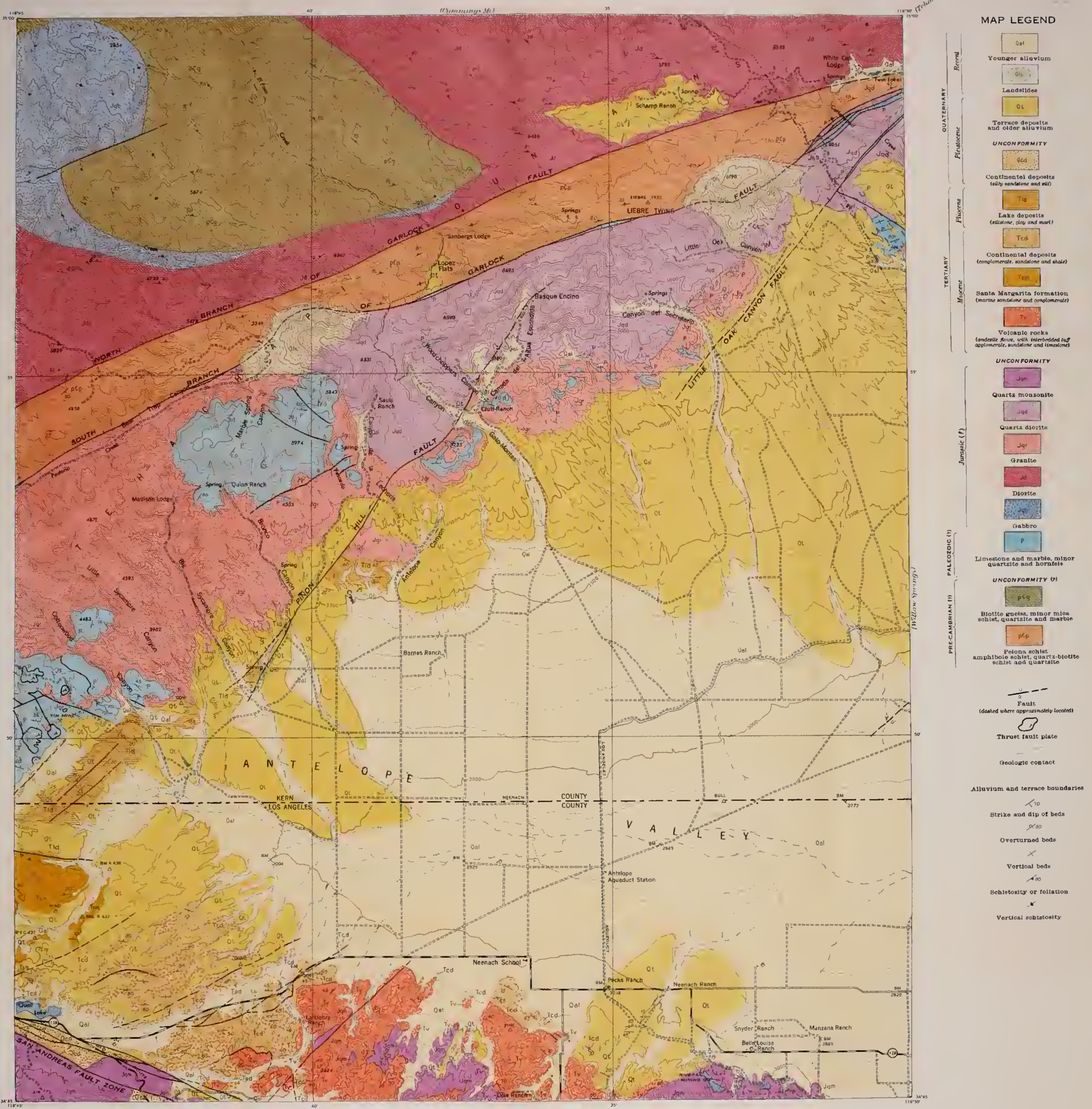

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GEOLOGIC MAP OF THE NEENACH QUADRANGLE CALIFORNIA

By John H. Wiese, assisted by Spencer F. Fine

Scale $\frac{1}{62500}$

Contour interval 100 feet
Datum is mean sea level

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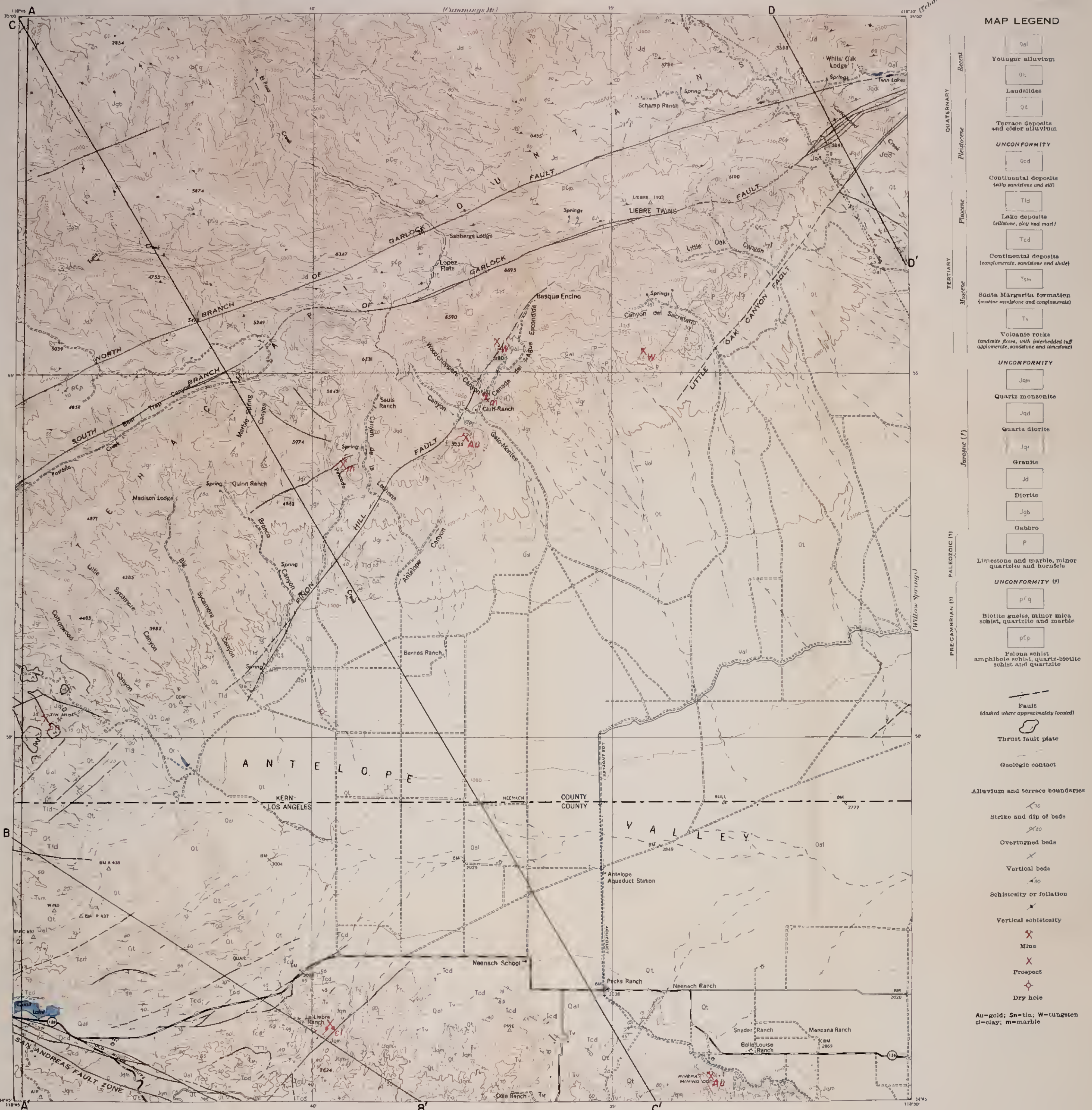

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Control by U. S. C. & G. S., U. S. G. S. and Fairchild Aerial Surveys, Inc.
Topography by Fairchild Aerial Surveys, Inc., by Stereophotogrammetric Process
Photography by Fairchild Aerial Surveys, Inc., Los Angeles, California 1943
Polyconic Projection, 1927 North American Datum

Geology surveyed in 1946

ECONOMIC MAP OF THE NEENACH QUADRANGLE CALIFORNIA

By John H. Wiese, assisted by Spencer F. Fine

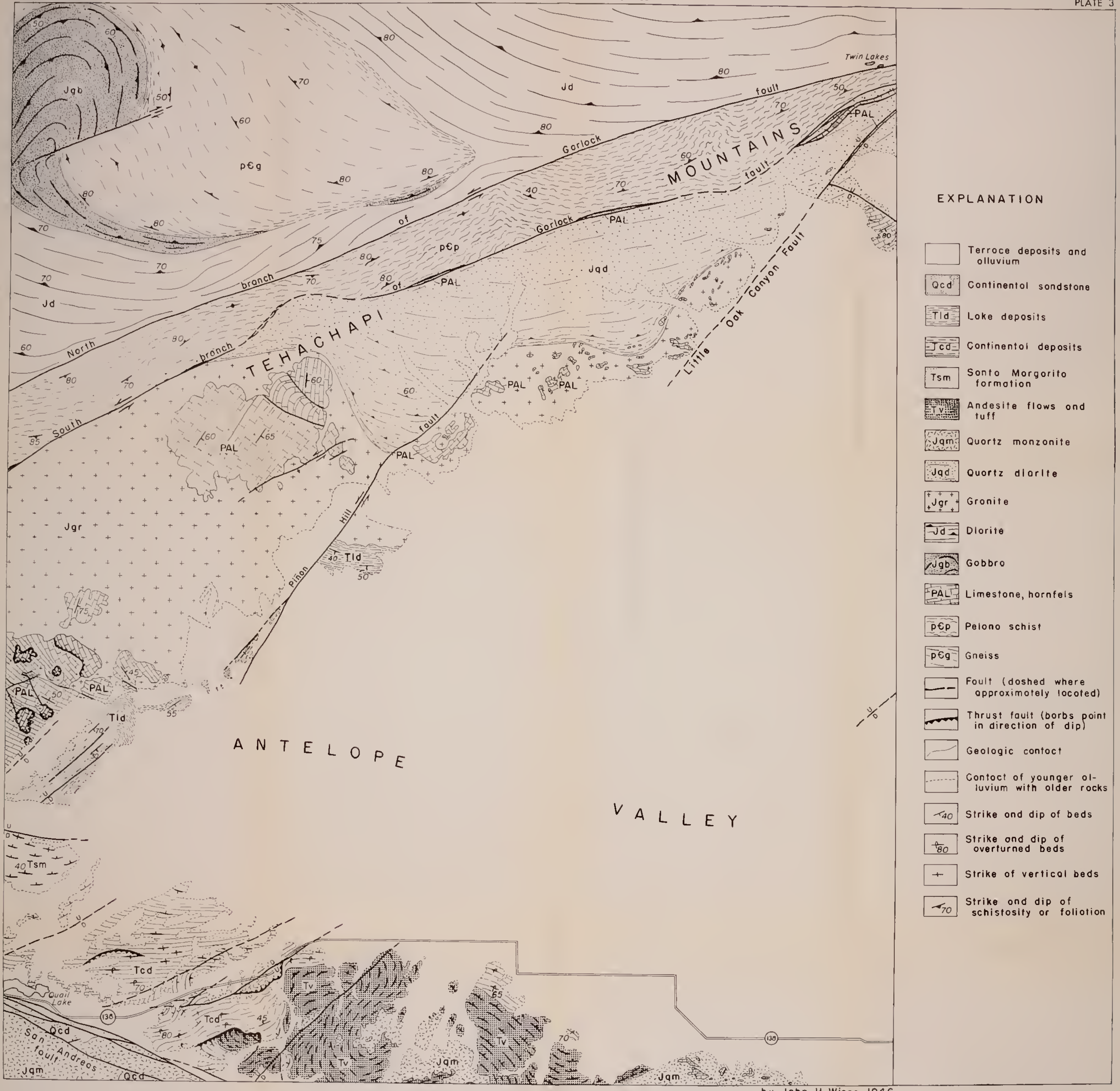
Scale 1/62500

Contour interval 100 feet
Datum is mean sea level

DIVISION OF MINES
OLAF P. JENKINS, *Chief*

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

BULLETIN 153
PLATE 3


EXPLANATION
Qcd Continental sandstone
Terrace deposits and alluvium
Tld Lake deposits
Tcd Continental deposits
Tsm Santa Margarita formation
Tv Andesite flows and tuff
Jqm Quartz monzonite
Jqd Quartz diorite
Jgr Granite
Jd Diorite
Jgb Gabbro
PAL Limestone, hornfels
p€p Pelona schist
p€g Gneiss
Fault (dashed where approximately located)
Thrust fault (barbs point in direction of dip)
Geologic contact
Contact of younger alluvium with older rocks
40 Strike and dip of beds
80 Strike and dip of overturned beds
Strike of vertical beds
70 Strike and dip of schistosity or foliation
TEHACHAPI MOUNTAINS
ANTELOPE VALLEY
North branch of Garlock fault
South branch of Garlock fault
Pinon Hill fault
Little Oak Canyon Fault
San Andreas fault
Twin Lakes
Quail Lake
138
Jgb
Jd
p€g
p€p
Jqd
Jgr
PAL
Tld
Tsm
Tcd
Tv
Jqm
Qcd

by John H. Wiese, 1946

STRUCTURE SKETCH OF THE NEENACH QUADRANGLE

0 1 2 3 4 5 6 7 8 9 10 Miles

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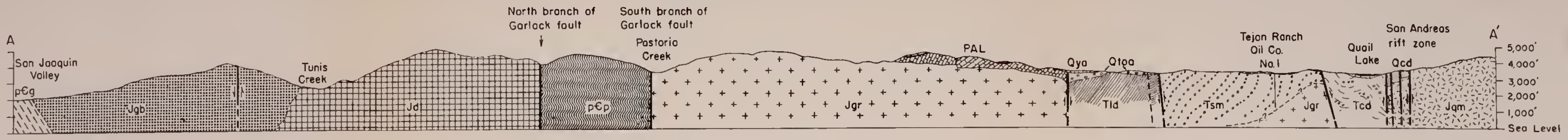
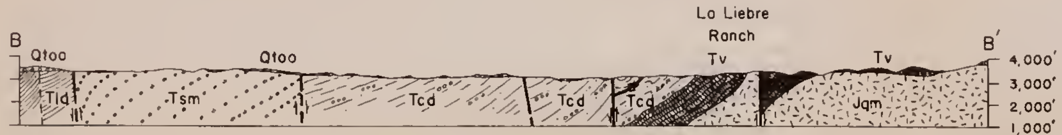
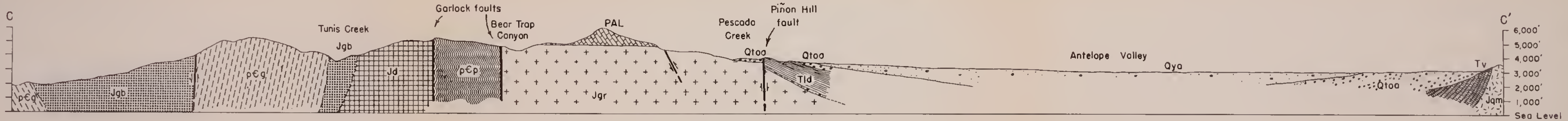
PLATE 4



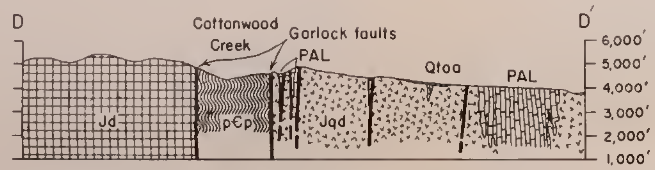
Section along line A-A′



Section along line B-B′



Section along line C-C′

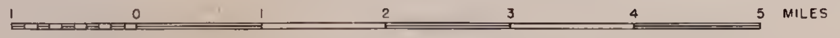


Section along line D-D′

EXPLANATION

Qya Alluvium	Tld Lake deposits	Jqm Quartz monzonite	PAL Limestone, hornfels
Qtoa Terrace deposits and older alluvium	Tcd Continental deposits	Jqd Quartz diorite	p€p Pelona schist
Qcd Continental sandstone	Tsm Santa Margarita formation	Jgr Granite	p€g Gneiss
	Tv Andesite flows and tuff	Jd Diorite	Fault
		Jgb Gabbro	

GEOLOGIC SECTIONS OF THE NEENACH QUADRANGLE, CALIFORNIA



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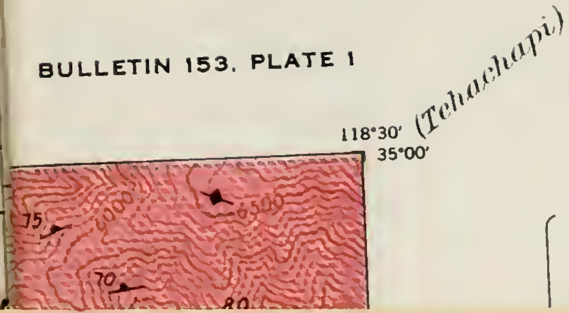
GEOLOGY

BULLETIN 153, PLATE 1



MAP LEGEND

Qal

4 plates